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SATELLITE (ACTS): WILL IT BENEFIT

COMMERCIAL/MILITARY SATELLITES?

by

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B.S., Troy State University, 1983

A thesis submitted to the

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NASA's Advanced Communications Technology Satellite (ACTS):

Will It Benefit Commercial/Military Satellites?

Thesis directed by Professor Floyd K. Becker

In 1978 NASA began research and development activities to determine needed technological advancements for the next generation of satellite communications systems. From this beginning evolved the Advanced Communications Technology Satellite (ACTS) program.

The purpose of the ACTS is to develop and flight-test high-risk technologies necessary for the United States' continued growth and preeminence in the field of satellite communications. NASA identified the key technologies of onboard baseband processor, microwave switch matrix, multiple beam antennas with electronically hopping narrow spot beams, automatic rain fade compensation, and Ka band (20/30 GHz) components for inclusion in the ACTS program.

With the ACTS scheduled for launch in 1992, this thesis determines whether or not the program will provide the desired benefits to commercial and military satellites. This determination is reached by first reviewing the technologies of the ACTS as well as those of present and planned communications satellites in commercial and military sectors. By comparing the reviewed technologies, a conclusion about the ACTS' ability to fulfill NASA's goal is reached.

In the course of the technology review and comparison it becomes obvious that the ACTS is not an end-all answer. It does, however, provide desirable benefits to commercial and military satellites allowing NASA to achieve its goal.

DEDICATION

This thesis is dedicated to my wife, Amy,
whose constant love, assistance, and
patience enabled me to complete
my degree requirements.

ACKNOWLEDGEMENTS

I acknowledge and thank the members of my thesis committee; Professor Becker, Professor Shain, and Professor Maley; for their time, effort, and assistance in helping me complete this thesis.

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CHAPTER I

INTRODUCTION

Purpose of the ACTS

The purpose of the Acts as stated by NASA is to develop and flight test high-risk technologies necessary for the United States' continued growth and preeminence in the field of satellite communications. The technologies NASA has identified for the ACTS are as follows:

- on-board baseband processor
- microwave switch matrix
- multiple beam antenna with electronically hopping narrow spot beams
- automatic rain fade compensation
- Ka-band (20/30 GHz) components

Comparison Technologies

This thesis will compare these ACTS technologies with the technologies of present or already planned military and commercial satellite systems in an attempt to determine the need or desirability of the ACTS program. The ACTS rain fade compensation abilities will be judged against actual needs. For comparison purposes the military's Defense Satellite Communications System

(DSCS) III and DSCS Follow On will be used along with INTELSAT's Satellite V and VI. The comparison systems include presently orbiting systems as well as their follow-ons which are either preparing for launch or are being planned with specific technologies and capabilities already determined.

Arrangement of the Thesis

This thesis will cover first the basic definitions of satellite terms and the criteria used to judge satellite systems and then look at each of the three systems independently. With technologies and capabilities of the systems established, a comparison will be made and a conclusion drawn as to whether or not NASA's ACTS truly will provide needed, flight-tested technologies or if present and planned commercial and military technologies have outstripped the ACTS of its usefulness to the continued growth and preeminence of satellite communications in the United States.

CHAPTER II

SATELLITE BASICS

In order to objectively evaluate satellite systems, definitions of satellite terms and criteria must be established. Terminology for specific system measurements will be defined and derived as necessary. The system criteria will be identified in the areas of ground and space segments. The ground segment is comprised of the control facility and the earth stations while the space segment is made up of the spacecraft itself.

Important measurements for satellite systems include: Effective Isotropically Radiated Power (EIRP), Gain (G), Noise Power (Pn), Carrier-to-Noise Ratio (C/N), Power Received (Pr), Path Loss (Lp), Efficiency (η), Attenuation (A), Data Rate in bits per second (bps), and Figure of Merit (G/T).

Gain

The gain of an antenna is the ratio of power radiated by an antenna configuration over that from an isotropic radiator emitting the same total power.[1] In this context, an istropic radiator is one in which the power is emitted equally and uniformly in all directions. This is an idealization which cannot be realized physically, but is a useful reference.[2] Gain of a receiver is calculated as:

$$G_r = \eta\left[\frac{4\pi\ Ae}{\lambda^2}\right]$$

where Ae is the effective aperture of the antenna (aperture area multiplied by efficiency) and λ is the free space wavelength.[3] Efficiency (η) is simply a measure of the actual performance an antenna can deliver. It is less than 100 percent because of losses due to reflection and absorption of some of the energy which strikes the antenna.

EIRP

EIRP is a representation of the actual power transmitted by an antenna and is expressed in decibels relative to 1 watt (dBw). The dBW is:

$$10\ \log_{10} \frac{\text{Power (W)}}{1\text{W}}$$

EIRP is equal to the gain of the antenna multiplied by the transmitted output power.[4]

Carrier-to-Noise Ratio

Carrier-to-Noise Ratio (C/N) is the ratio of the received unmodulated carrier power to the noise power at the demodulator input. To obtain this figure we must first determine the power received (Pr) which is the signal power delivered by the antenna to the receiver at the input to the radio frequency amplifier (RF). It is:[5]

$$Pr = (EIRP + Lp - La)dBW$$

Path loss (Lp) is:

$$L_p = 10 \log_{10}[(\frac{4\pi R}{\lambda})^2]$$

where R is the distance in meters. Lp is a loss which accounts for the way energy spreads out as an electromagnetic wave travels from a transmitting source.[6] Atmospheric loss (La) is usually written as the sum of atmospheric absorption, a constant term, and attenuation (A), a variable term. If a satellite link has more power than it needs to transmit signals in clear weather, this is called its clear weather link margin. This margin is usually expressed in dB and can be thought of as extra power for transmitting during bad weather or other forms of interference. At most frequencies atmospheric losses are minimal, less than 0.05 dB for a one-way geosynchronous path of 22,300 mi., but it should be noted that at 22.235 GHz the resonant frequency of water vapor can cause attenuation of almost 1 dB for the same link.[7] Long-term increases in attenuation are called fades. Rain fades are a particular problem above 10 GHz, worsening as the rate of rain and frequency of the signal increases. The rate at which the rain falls in millimeters per hour (mm/hr) determines the severity of attentuation for a given frequency that the signal will suffer. Rain rates are given as a percentage of time during a year for which a specified rate can be expected to exceed a given value. For example, for 1 percent of the year (87.6 hrs) in Tampa, Florida a rain rate of 6 mm/hr could be expected to be exceeded. Based on this and other information such as earth station look angle, elevation above sea level, and signal frequency, the amount of rain fade attenuation (in dB) can be calculated for 1 percent of the year. This also means that for 99 percent of the year, this amount of rain fade would not affect the earth station. So if the rain fade for 1 percent of the year exceeded the earth station's link margin, then the earth station could be expected to be available for only 99 percent of the year (100 percent - 1 percent down time due to rain fade = 99 percent). Detailed rain fade calculations can be found in the Appendix, and are specifically referenced in the following chapters. Another problem with rain is its ability to attenuate a signal by depolarizing overlapping frequency bands using orthogonal polarization for separation.[8]

The power received (Pr) multiplied by the overall radio frequency (RF) and intermediate frequency (IF) gain (G, as a ratio, not dB) of the receiver gives the power contained in the carrier (C) and sidebands after amplification and frequency conversion within the receiver. Noise Power (Pn) is:

$$Pn = kTnB$$

where k = Boltzmann's constant = 1.38×10^{-23} J/K = -228.6 dBW/K/Hz, Tn = noise temperature of the source in degrees Kelvin, B = bandwidth of power measurement device in hertz, and Pn is the available noise power and will only be delivered to a device that is impedance matched to the source.[9] The total noise power figure (N) is obtained using the noise temperature of the entire system (Ts), the gain of the receiver, and its narrowest bandwidth B giving:

$$N = kTsBG$$

This results in an overall carrier-to-noise ratio formula at the demodulator of:

$$\frac{C}{N} = \frac{(Pr\ G)}{(k\ Ts\ BG)} = \frac{Pr}{k\ Ts\ B}$$

Figure of Merit

Figure of Merit (G/T) is used to characterize earth stations and is the antenna gain to noise temperature ratio. It is normally expressed in dBK^{-1} which is obtained by converting the system noise temperature into dBK. G/T is:[11]

$$G/T = Gr \text{ in dB} - 10 \log (Ts \text{ in Kelvins})\ dBK^{-1}$$

Data Rates

Since the inherent value of communications satellites is dependent upon the amount of information they can transmit, data rates are an important criterion in system comparisons. Simply stated, the data rate of a signal is the rate, in bits per second, that data is transmitted.[12] Channel rates are important as well as overall system rates, because channel rates can represent the usefulness of the satellite to a small individual user who may be sharing in the overall system capability with a variety of other small and large users. Channel data rates also allow a more equitable comparison of satellites of different sizes. The bit error rate (BER) which is the fraction of a sequence of message bits that are in error is also an important system consideration.[13] Another useful subdivision of communications capabilities on the satellite is the transponder. The combination of a satellite receiver unit and its associated transmitter unit in a one-to-one correspondence represents a transponder. Capabilities of a transponder are usually noted as bandwidth of the unit or data rate in bits per second (bps).

Utilized Frequencies

Frequencies used on the following systems include Ultra High Frequency (UHF), Super High Frequency (SHF), Extremely High Frequency (EHF), and Ka, C and K band frequencies. UHF encompasses frequencies from 300 MHz-3 GHz while SHF goes from 3-30 GHz. EHF runs from 30-300 GHz with the Ka band from approximately 20-45 GHz. C band represents 6/4 GHz and K band 14/11 GHz.[14]

Comparison Criteria

In the following chapters the ACTS, DSCS III, DSCS F, Intelsat V, and Intelsat VI will be presented. Following this a comparison of the systems will be made. The comparison will be based on several technical aspects, system capabilities and subjective inputs as provided by satellite industry representatives. Information on satellite control facilities will only be considered to the extent these facilities enhance or degrade the performance and cost effectiveness of the system as a whole. Particular criteria for the reader to observe are the technical capabilities of the system, achievable data rates represented in bps, bit error rates, the gain and EIRP of the spacecraft antenna as well as the G/T of the earth stations, the overall C/N as well as the uplink and downlink C/N, the atmospheric losses suffered by the systems since they represent different operational frequencies, and of course the merit of the technologies they provide.

NOTES--CHAPTER II

[1]Timothy Pratt and Charles Bostian, Satellite Communications (New York: John Wiley and Sons, 1986), p. 109.

[2]Ibid., p. 108

[3]Ibid., p. 110.

[4]Ibid., p. 448.

[5]Ibid., p. 110.

[6]Ibid.

[7]Ibid., p. 324.

[8]Ibid., pp. 328, 319.

[9]Ibid., p. 113.

[10]Ibid., p. 114.

[11]Ibid., pp. 450, 354.

[12]William Stallings, Data and Computer Communications, 2nd ed. (New York: Macmillan, 1988), p. 69.

[13]Pratt and Bostian, p. 447.

[14]BDM International, Inc., Electromagnetic Spectrum (McLean, Virginia: BDM, 1987).

CHAPTER III

NASA'S ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS)

The Advanced Communications Technology Satellite (ACTS) represents NASA's efforts to develop and flight-test high-risk technologies necessary for the United States' continued growth and preeminence in the field of satellite communications. The key technologies to be verified on the ACTS include:

- baseband processor
- microwave switch matrix with satellite switched time division multiple access (SS/TDMA)
- multiple beam antenna with electrically hopping narrow spot beams
- automatic rain fade compensation
- Ka-band (20/30 GHz) components

A planned intersatellite laser communications payload was deleted due to lack of funding. Other technologies and information included are: physical description of spacecraft, steerable gimbaled-dish antenna, Serial Minimum Shift Keying modulation, and earth station antenna characteristics. This chapter will provide an overview of technologies as well as the benefits provided by these technologies.

Physical Description of Spacecraft

The approximate dimensions and appearance of the fully deployed ACTS are depicted in Figure 1. The ACTS will utilize momentum wheels for three-axis stabilization once it achieves its operational orbit.

The ACTS is scheduled for launch in 1992 and has an expected life of three years during which time experiments will be conducted to test its technologies.

Multiple Beam Antenna

The ACTS Multiple Beam Antenna (MBA) provides the interface between the flight system and the earth portion of the communications system. The MBA provides for three fixed spot beams for high burst rate operations and two scanning beams for low burst rate operations. The scanning beams provide coverage for two sectors (East and West) and 13 spot beam coverages.[1] These coverages are shown in Figure 2. The MBA is made up of two separate high-gain, offset, cassegrain antennas with receive antenna operation at 30 GHz and the transmit antenna at 20.2 GHz. Each of these antennas includes two polarization-selective hyperbolic subreflectors arranged in a piggyback configuration.[2] The antennas are each capable of using two beam-forming network (BFN) arrays and three fixed beams. The BFN arrays function at orthogonal polarizations with one using the front subreflector and

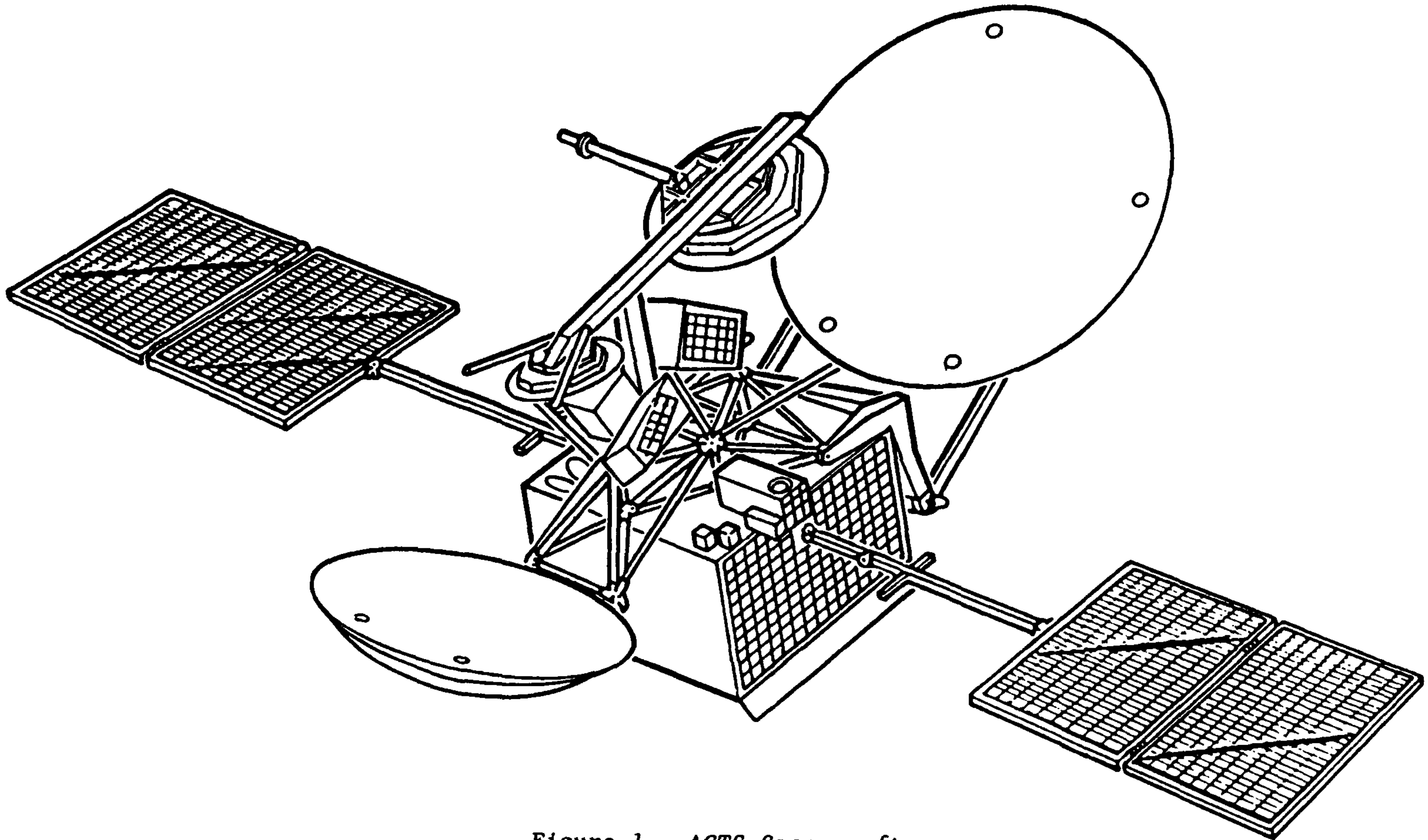

Figure 1. ACTS Spacecraft.

Source: Michael Naderi and Joseph Campanella, NASA's Advanced Communications Technology Satellite (ACTS) (Arlington, Virginia: AIAA 12th International Communications Satellite Systems Conference, 1988), p. 17.

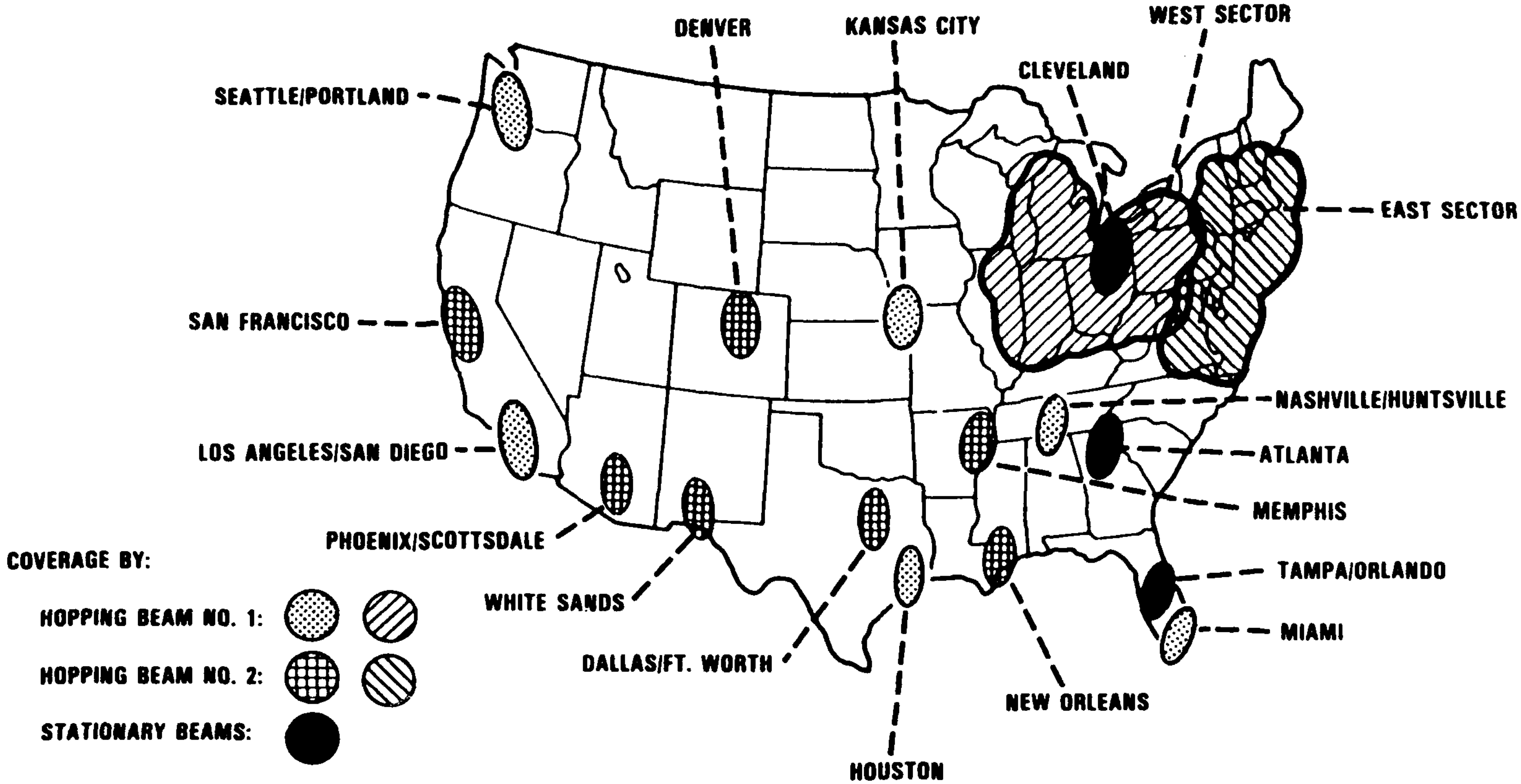

Figure 2. ACTS MBA Coverages.

Source: Michael Naderi and Joseph Campanella, NASA's Advanced Communications Technology Satellite (ACTS) (Arlington, Virginia: AIAA 12th International Communications Satellite Systems Conference, 1988), p. 2.

the other using the rear subreflector. This can take place because the front reflector only reflects the polarization of one of the arrays, while letting the polarization of the second signal pass through to the rear subreflector where it is reflected into the main antenna (Figure 3). This allows for the frequency reuse of both the receive and transmit frequencies while providing for two separate polarized beams on each antenna. The BFN network arrays provide the basis for the hopping beam. The arrays consist of 44 radiating or receiving elements whose phase and gain can be adjusted to shape the beam and "point" the antenna to the proper location, allowing faster and less bulky control of the beam compared to conventional mechanical pointing.[3] The up and down beams do not need to point to the same earth location simultaneously due to the capabilities of the Baseband Processor (BBP) which will be discussed later. The three fixed beams (up and down) are functionally separate from the BFN, but their electronics are housed within the same unit. The fixed beams are utilized by the Microwave Switch Matrix, also discussed later, and are not involved with the BBP mode. The Atlanta and Tampa beams use the same frequency and polarization, but rely on spatial diversity to achieve the necessary isolation.[4] The size of the MBA antenna allows it to generate narrow 0.27-degree spot beams with an associated gain that is nearly 20 dBW greater than the typical seven-degree beamwidth of a conventional communications satellite having CONUS coverage. This gain increase allows

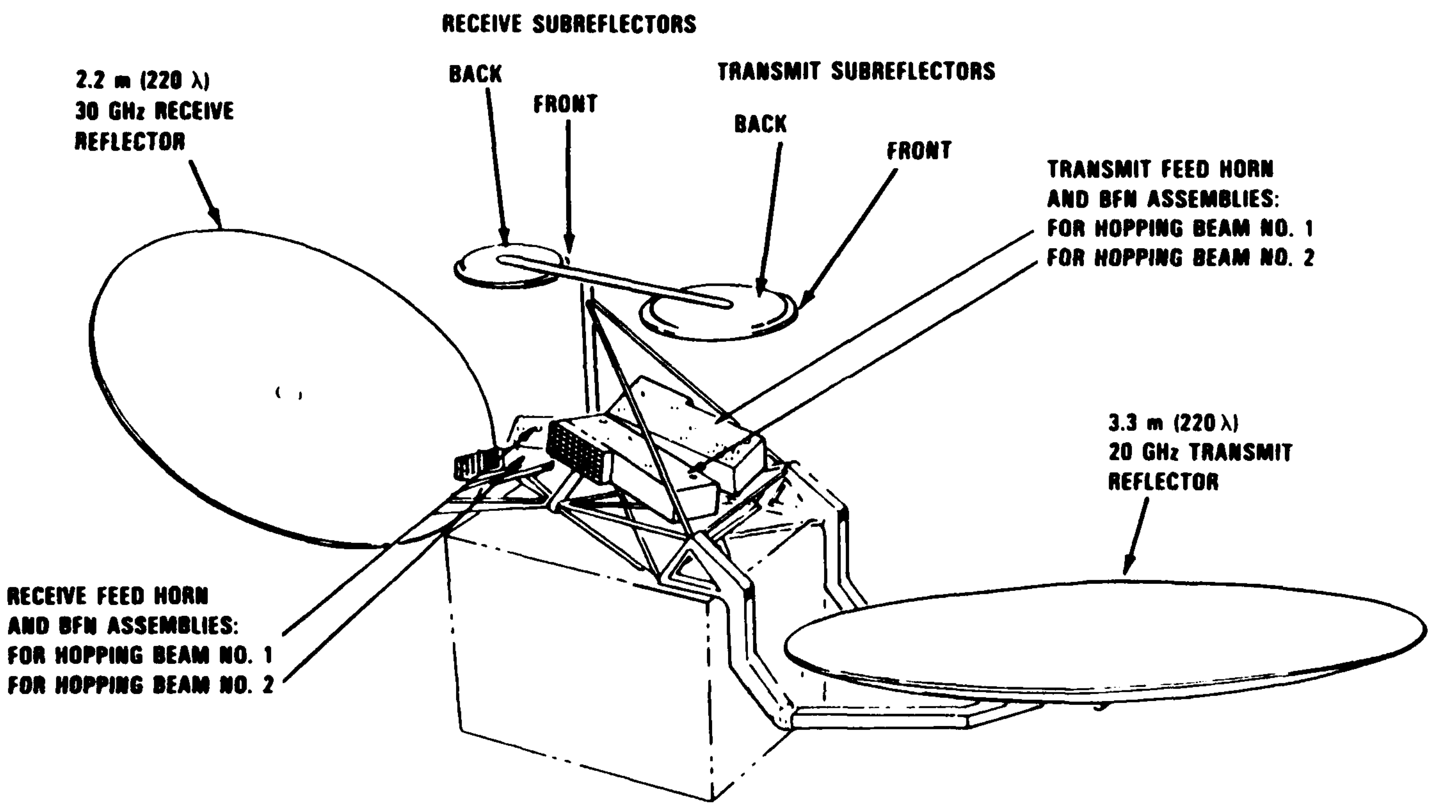

Figure 3. ACTS MBA Components.

Source: Michael Naderi and Joseph Campenella, NASA's Advanced Communications Technology Satellite (ACTS) (Arlington, Virginia: AIAA 12th International Communications Satellite Systems Conference, 1988), p. 5.

multi-megabit-per-second throughput at each earth station while maintaining small antenna sizes of approximately 6.7 ft., and a transmitter power of less than 10 watts.[5] A typical 8 ft. antenna transmitting at 30 GHz has a gain of 55.3 dBW and with a transmitter power of 10 watts achieves a net EIRP of 64 dBW. A slightly larger 8.3 ft. antenna receiving at 20 GHz has a gain of 51.8 dB and a G/T of 23.8 dB.[6] The ACTS is expected to be able to operate with ground terminal antennas ranging in size from ′ ft. to 16.7 ft.[7] The flight system also contains a mechanically steerable antenna with a one-degree beam width and a steering rate of one degree per minute.[8] This antenna can be directed to any portion of the earth visible to the ACTS and will allow the inclusion of Alaska and Hawaii into the area of communications coverage. This beam will also provide coverage for tracking the shuttle or a spacecraft in low-earth orbit.[9] Table 1 contains a listing of the gain, EIRP, and G/T for each of the ACTS beams.

Onboard Storage Baseband Switching

The operation of the ACTS in the Onboard Storage Baseband Switching (OSBS) mode utilizing Time Division Multiple Access (TDMA) is probably the most unique aspect of this experimental satellite. Unlike typical "bent pipe" satellite repeaters or intermediate frequency (IF) switches, the ACTS Baseband Processor (BBP) actually demodulates the input signal, stores it, decodes it if necessary, routes it, stores it, recodes it if necessary, and

Table 1. ACTS EIRP and G/T Summary

Beam	Receive Polarization[a]	Gain (Edge of coverage), dB[b] Receive	Transmit	EIRP, DBW	G/T, dB
Hopping Beams					
Beam No 1					
Houston	H	50.8	50.6	62.7	19.3
Kansas City	H	50.9	50.7	62.8	19.4
L.A./San Diego	H	49.2	48.1	60.0	17.5
Miami	H	50.6	50.3	62.5	19.0
Nashville/Huntsville	H	50.9	50.8	62.9	20.0
Seattle/Portland	H	49.1	48.3	60.0	17.5
East Scan Sector	H	47.7	46.3[c]	60.0	16.9
Beam No. 2					
Dallas	V	49.2	50.6	62.7	17.3
Denver/Colorado Springs	V	48.9	50.2	62.3	16.9
Memphis	V	49.5	50.9	63.1	17.4
New Orleans	V	49.3	50.8	63.0	17.3
Phoenix/Scottsdale	V	48.5	48.8	60.8	16.6
SF/Sacramento	V	48.1	46.1	57.6	15.9
White Sands	V	48.9	49.8	61.8	16.8
West Scan Sector	V	46.1	46.6[c]	60.0	14.7
Stationary Beams					
Cleveland	H	50.5	51.3	57.9/64.1[d]	19.8
Atlanta	V	50.0	51.4	57.9/64.1	18.6
Tampa	V	50.0	51.0	57.4/63.6	18.9
Mechanically Steerable				54.4	11.3

[a]In all cases transmit polarization is orthogonal to receive polarization.

[b]Edge-of-coverage gain for spot beams is defined at 0.27 deg and is nominally 2-dB less than the peak.

[c]Minimum gain over 90% of the scan sector.

[d]Low/high power mode

Source: Michael Naderi and Joseph Campanella, NASA's Advanced Communications Technology Satellite (ACTS) (Arlington, Virginia: AIAA 12th International Communications Satellite Systems Conference, 1988), p. 8.

modulates it back out. If necessary, the BBP can perform decoding and coding of the signal for rain fade protection. This is shown schematically in Figure 4. As an example, we will follow a signal being sent from Tampa to Denver. By monitoring the strength of beacon signals transmitted from the ACTS, the Tampa and Denver earth stations can determine whether or not they are

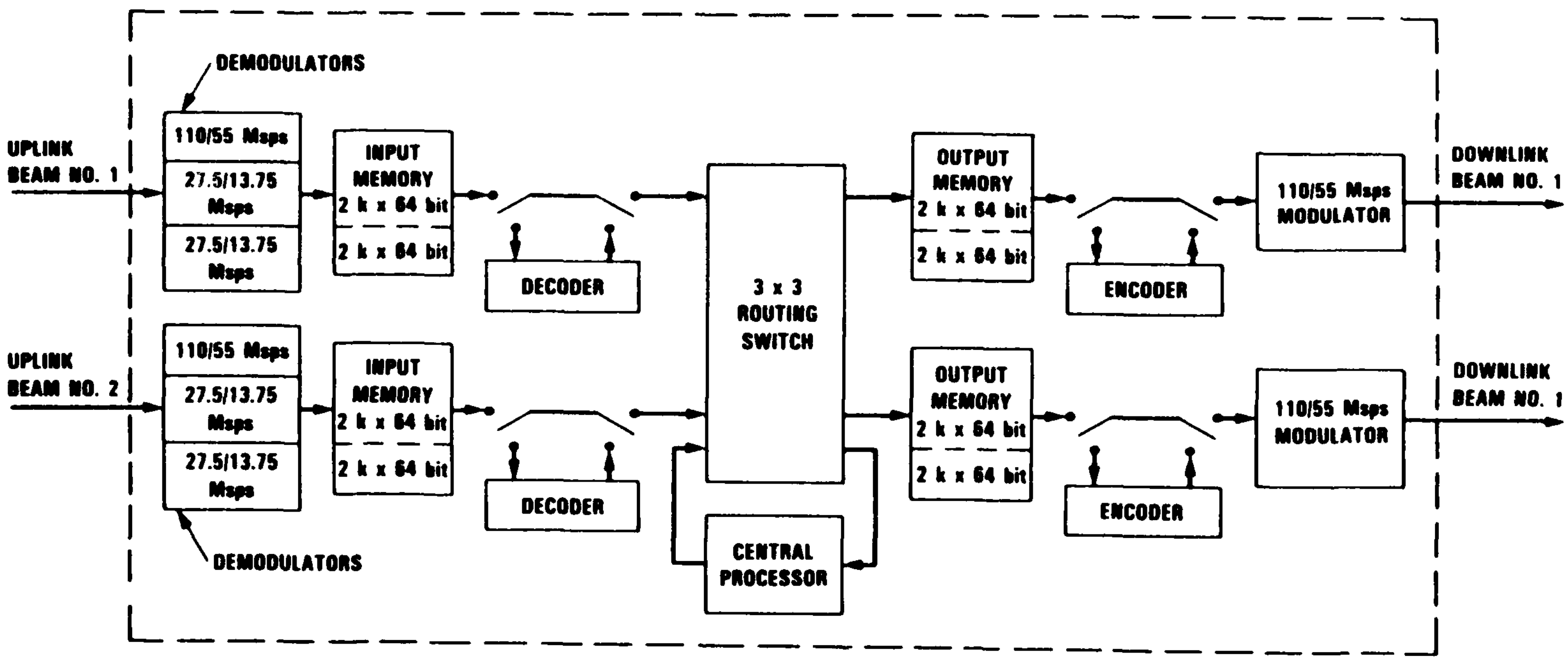

Figure 4. ACTS Baseband Processor.

Source: Michael Naderi and Joseph Campanella, NASA's Advanced Communications Technology Satellite (ACTS) (Arlington, Virginia: AIAA 12 International Communications Satellite Systems Conference, 1988), p. 11.

experiencing rain fading. If so, the affected earth station sends a request through the ACTS to the Master Control Station (MCS) and requests fade protection. If an earth station experiences rain fading on its up and/or down link, transmissions to and/or from that station are commanded from the MCS to be Forward Error Correction (FEC) coded. FEC along with other measures described later is supposed to allow transmissions to overcome rain fade attenuations. Let's assume both Tampa and Denver are experiencing rain fade. In this situation the ACTS would receive a Tampa transmission that was FEC encoded. The ACTS' BBP would first demodulate the Tampa signal to its original frequency before transmission and store it in an input memory and then decode the FEC to return the signal data to its original state. The BBP then routes the data through the switch to an output memory. From there the data is then encoded again to help overcome Denver's fade problem and modulated up to its transmission frequency. The FEC and modulated signal is then transmitted to Denver by the proper spot beam. The BBP features allow the important advantages of being able to dynamically reconfigure message routing to accommodate traffic changes and to individually apply forward error correction coding to overcome localized rain fading associated with Ka band operation.[10]

The BBP accepts one 110 Mbps channel or two frequency division multiplexed (FDM) 27.5 Mbps channels on an uplink beam with a constant downlink transmission rate of 100 Mbps. The ACTS has the capacity to accept four FDM 27.5 Mbps channels, but as an experimental system it was not built to its fullest potential (only two FDM 27.5 Mbps channels) to save weight on the spacecraft and tax dollars.[11] Therefore, there are three demodulators per uplink beam on the ACTS (one 110 Mbps, two 27.5 Mbps). This gives a maximum baseband processor throughput of 110 Mbps per beam, which for the two hopping beams gives a total maximum throughput of 220 Mbps in OSBS/TDMA mode.[12] The BBP utilizes a 1-millisecond TDMA frame and can simultaneously accept and process TDMA signals from the two uplink hopping beams.[13]

MBA OSBS Advantages

The hopping spot beams with the complex onboard baseband switch provides advantages over satellites using only IF or full-modulation switching. The electronically hopping spot beams function in a unique way. During a 1 ms TDMA frame a beam can hop to many locations (spots) dwelling long enough to pick up the offered traffic in the form of Uplink Traffic Bursts (UTBs).[14] Each TDMA frame is made up of many UTBs. In the BBP mode the ACTS receives the TDMA frame, processes it, and retransmits the Downlink Traffic Bursts (DTBs) in another 1 ms TDMA frame. For retransmission the downlink spot beam hops to many locations during the TDMA frame time and delivers the DTBs to the proper location. This process is why the spot beams are calling "hopping."

In non-baseband satellite switches, the earth stations have to time their data bursts at multiple intervals to correspond with the time period when the satellite switch is connected to the desired downlink. The baseband switch with its dynamic processing and routing switch allows the earth station to transmit all of its traffic in one burst and requires the satellite to worry about the timing required to get the traffic out on the right downlink, thereby reducing the earth station overhead. The BBP knows where to route received signals because of information from the orderwire system. Each UTB transmitted by an earth station has a two-word (128 bits) inbound orderwire. The BBP strips out all of inbound orderwires and combines them into a DTB to the Master Control Station (MCS). The MCS sends a Control Burst (orderwire) which carries instructions to the control memories of the BBP. These memories control the BBP channel routing and MBA beam-hopping sequence.[15] An outbound orderwire from the MCS provides information to the earth stations such as circuit assignment, uplink and downlink burst position assignments, and other commands.[16] This complexity and cost in the satellite are offset through the savings realized through a more efficient network particularly in a system which has many customer premises terminals carrying light traffic that are to be networked together.[17] It is additionally obvious that with this system, earth stations can be connected in a mesh topology with total interconnection. This is a definite advantage to present-day Very Small Aperture

Terminal (VSAT) networks which use a star topology with all VSAT to VSAT communications being routed through a central earth station hub. The star topology requires two hops for end-to-end transmission whereas the ACTS' mesh would only use one. The excessive delay of the double hop (480-600 ms) makes voice communications unacceptable, but with the ACTS single hop (240-300 ms), duplex voice between and two locations becomes acceptable.[18] This definition of "acceptable," however, should probably be taken in the context of people in favor of satellite communications and not of people accustomed to the virtual lack of any delay provided by terrestrial systems. The OSBS also provides several dB of link improvement since the input signals are regenerated and noise is not cascaded through the entire link.[19]

Satellite Switched Time Division Multiple Access

In the Satellite Switched (SS)/TDMA mode the ACTS uses a Microwave Switch Matrix (MSM) to route traffic to and from the MBA. The MSM operates at an IF of 3 GHz and provides no onboard storage, or processing other than switching.[20] The MSM receives input from up to three stationary beams. These three beams can be the three fixed beams from the MBA or any two of the hopping beams' locations can be set in a stationary position and used with one of the fixed beams. If stationary hopping beams are used, they must replace the Tampa or Atlanta fixed beams since the Cleveland beam, which is used by the network master control station, must always be included.[21] The MSM itself is a solid-state, programmable "cross-bar" switch that provides direct connectivity for the three beams (Figure 5). The MSM also uses a 1-millisecond TDMA frame and normally works with SMSK modulation, but it is not restricted to SMSK as is the OSBS.[22] The data rate in the SS/TDMA mode can vary up to a maximum of 220 Mbps per beam for a total maximum MSM throughput of 660 Mbps for the three beams.[23] The MSM functions the same as the IF switch described earlier in that the satellite switch state changes several times during a frame to account for the different end-to-end combinations and the earth station must wait for the appropriate time to send signals to a particular destination (Figure 6). This requires an earth station to transmit uplink bursts several times during a single TDMA frame. The preambles, guard times, and other associated overhead makes this technique relatively inefficient, particularly for a system with many terminals carrying low traffic loads that are split into multibeam traffic and are best served by the OSBS mode. The SS/TDMA mode is; however, reasonable and normally used in networks where interbeam traffic is heavy and among a relatively small number of terminals defined as less than 100.[24] The relationship between the MBA, MSM, and BBP is shown schematically in Figure 7.

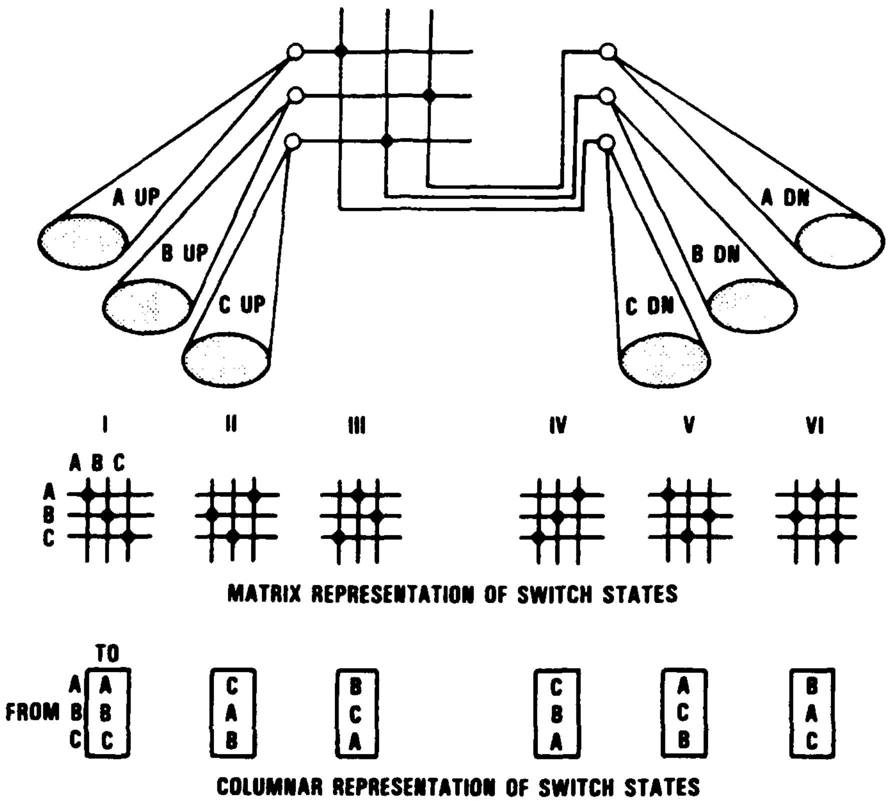

Figure 5. ACTS MSM SS/TDMA Switching States.

Source: Michael Naderi and Joseph Campanella, NASA's Advanced Communications Technology Satellite (ACTS) (Arlington, Virginia: AIAA 12 International Communications Satellite Systems Conference, 1988), p. 24.

Serial Minimum Shift Keying Modulation

The ACTS utilizes Serial Minimum Shift Keying (SMSK) modulation and has a frequency division multiplexing (FDM) capability on the uplinks while in the OSBS/TDMA mode. The SMSK modulation is required for the BBP, but the ACTS' Microwave Switch Matrix is more flexible and has the capability to utilize other

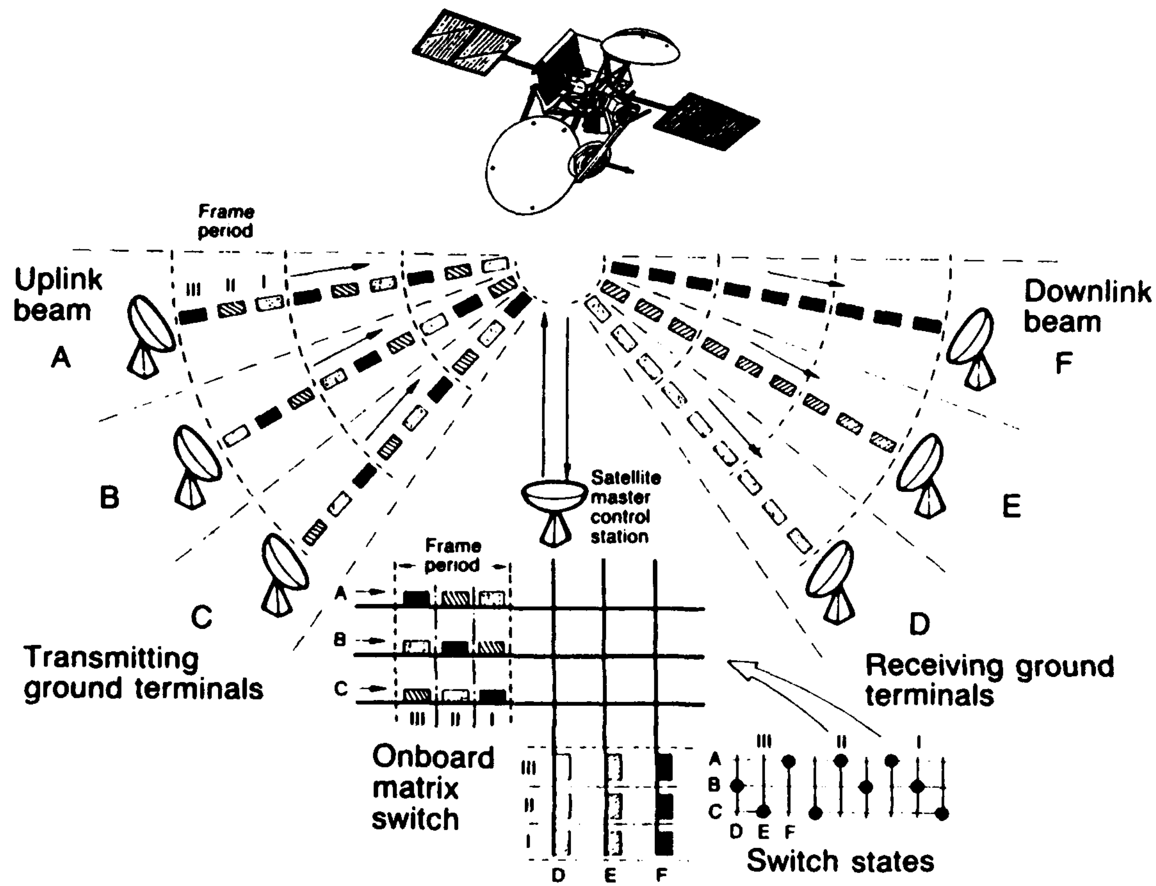

Figure 6. SS/TDMA Using MSM.

Source: NASA, Experiments Applications Guide (Cleveland, Ohio: Lewis Research Center, July 1988), p. 13.

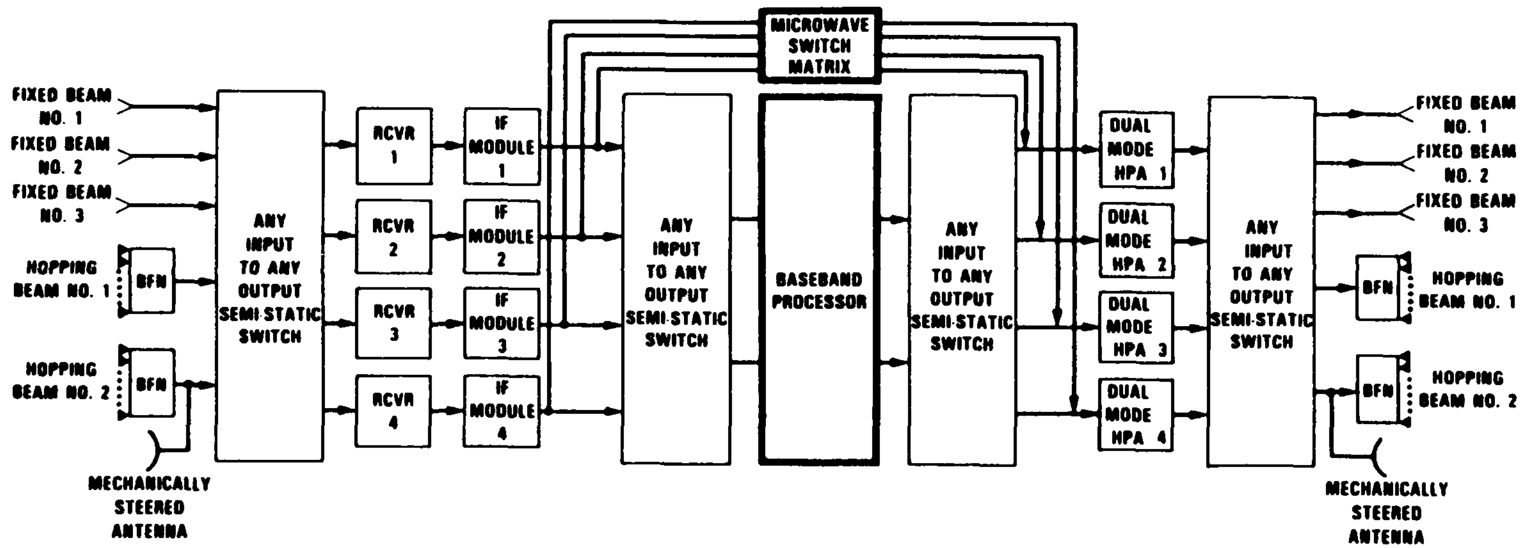

Figure 7. ACTS MBA, MSM, BBP Relationship

Source: Michael Naderi and Joseph Campanella, NASA's Advanced Communications Technology Satellite (ACTS) (Arlington, Virginia: AIAA 12th International Communications Satellite Systems Conference, 1988), p. 3.

modulation techniques. The SMSK modulation uses the same bandwidth as Bi-Phase Shift Keying (BPSK) but, it is easier to generate. SMSK is not as bandwidth efficient as other modulation schemes such as Quadrature Phase Shift Keying (QPSK) which is 50% more bandwidth efficient. However, since the ACTS utilizes large bandwidths the concern was placed on power efficiency which the SMSK has. SMSK can be used in transponders operating near saturation with less amplitude and phase modulation affects than with other modulation schemes.[25]

Rain Fade Compensation

Satellites operating in the 20 GHz/30 GHz (Ka band) frequency range are susceptible to localized rain fading and in order to combat this problem the ACTS uses a combination of dynamic fade-fighting techniques. In order to detect fade the ACTS flight system incorporates three beacons for real time fade measurements; two in the downlink frequency band and one in the uplink frequency band.[26] The beacon signals are continually received and processed by each ground terminal. Once the received beacon power drops below a certain threshold the affected terminal sends a request through the ACTS (by orderwire) to the network's Master Control Station (MCS) for fade protection.[27] The MCS takes different actions for the OSBS/TDMA and the SS/TDMA modes mainly due to the difference in their respective processing capabilities. For the OSBS/TDMA mode the MCS will instruct the affected terminal (uplink) and/or the ACTS (downlink) to FEC code its transmissions. The affected device employs a rate 1/2 convolutional coding/decoding scheme utilizing maximum-likelihood techniques which provides in excess of 4 dB link improvement at a constant bit error rate of $10E^{-6}$ relative to uncoded messages.[28] A convolutional code is one in which there is not a one-to-one correspondence between the original data bits and the coded bits.[29] The rate 1/2 means that for each original data bit in, two coded bits will be output. The ACTS is able to only code the link(s) experiencing fade because the BBP is able to perform coding/decoding onboard the satellite itself. The MCS then instructs the affected device (terminal-uplink, ACTS-downlink) to apply a two-to-one symbol rate reduction.[30] This rate reduction provides an additional 6 dB increase in performance resulting in a net increase of 10 dB (4 dB from coding) over the designed 5 dB clear weather margin.[31] The rate 1/2 coding and factor of 2 rate reduction results in a transmission burst that is one-half of that during normal operation. Even though a total rate reduction of 4 has occurred, the transmission burst is only reduced to one-half because of a fade pool within the TDMA frame. The fade pool is made up of extra UTBs or DTBs so if a terminal is experiencing fade it can use its usual UTB as well as one from the fade pool. This allows the terminal to send two 1/4 UTBs within the TDMA frame for a total transmission burst of 1/2 the normal rate. Earth stations operating at 110 Mbps or 27.5 Mbps will transmit at 55 Msps or 13.75 Msps during fading, but the actual information rate remains unchanged making the whole operation transparent to the user.[32] While the information rate (total bits transferred) remains the same, the actual data rate (data bits transferred) is reduced by 1/2. The SS/TDMA mode does not have the ability to work with the baseband signal so it compensates for fading through increased power output. The power increase is implemented by commands from the MCS after a terminal suffers fading and requests protection in the same fashion as in the OSBS/TDMA mode. The MSM network is designed to accommodate 18 dB of uplink fade and 8 dB of downlink fade and to maintain a bit error rate of $10E^{-6}$ which is accomplished by increasing the uplink power by 10 dB (from the earth station) and increasing the downlink power by 6 dB (from the ACTS).[33]

While the ACTS has the ability to compensate for rain fade attenuation, from the calculations performed in the Appendix it appears the ACTS' BBP cannot completely compensate for expected fades in some locations. System planners state the ACTS is only an experimental system and is planned for a 99.9 percent availability rate versus 99.99 percent for an operational device.[34] For the Tampa, Florida region the ACTS clear-weather margin is adequate for 99 percent availability, but even with the rain fade compensation, an availability of 99.9 percent cannot be achieved. For a more arid climate, like that of Denver, Colorado the ACTS is able to maintain a 99.99 percent availability which exceeds the planned availability.

NOTES--CHAPTER III

[1]Y. H. Choung and W. C. Wong, "Multibeam Antenna Design and Development for NASA Advanced Communications Technology Satellite (ACTS)," IEEE Global Telecommunications Conference, Vol. 1, Dec. 1986, p. 568.

[2]Michael Naderi and Joseph Campanella, NASA's Advanced Communications Technology Satellite (ACTS) (Arlington, Virginia: AIAA 12th International Communications Satellite Systems Conference, 1988), p. 5.

[3]A. N. Downey, D. J. Connolly, and G. Anzio, "MMIC Technology for Advanced Space Communications Systems," Seventeenth Annual Electronics and Aerospace Conference, Washington, D.C., 1984, p. 1.

[4]Naderi and Campanella, p. 6.

[5]Robert Bauer, "You're Invited to Participate in a NASA Program That's Pioneering Future Satcom Technologies," Communications News, March 1988, p. 45.

[6]Naderi and Campanella, p. 28.

[7]NASA, ACTS, The Next Generation of Space Communications (Cleveland, Ohio: Lewis Research Center, n.d.), p. 8.

[8]Naderi and Campanella, p. 2.

[9]R. J. Schertler, "ACTS Experiments' Program," IEEE Global Telecommunications Conference, Vol. 1, p. 586.

[10]R. Moat, "ACTS Baseband Processor," IEEE Global Telecommunications Conference, Vol. 1, p. 578.

[11]Telephone interview with Robert Bauer, Experiments Program Engineer, Lewis Research Center, NASA, 4 Nov. 1988.

[12]Naderi and Campanella, p. 11.

[13]Grabner and Cashman, p. 562.

[14]Naderi and Campanella, p. 20.

[15]Ibid., p. 21. [16]Ibid.

[17]Ibid., p. 14.

[18]Bauer, "You're Invited," p. 45.

[19]Naderi and Campanella, p. 4.

[20]Ibid., p. 12. [21]Ibid., p. 4.

[22]Grabner and Cashman, p. 563.

[23]Naderi and Campanella, p. 12.

[24]Ibid., p. 14.

[25]Letter from Robert Bauer, Experiments Program Engineer, Lewis Research Center, NASA, 7 Nov. 1988.

[26]Schertler, p. 585.

[27]Naderi and Campanella, p. 9.

[28]Moat, p. 580.

[29]Timothy Pratt and Charles Bostian, Satellite Communications (New York: John Wiley and Sons, 1986), p. 448.

[30]NASA, Experiments Applications Guide (Cleveland, Ohio: Lewis Research Center, July 1988), p. 24.

[31]Naderi and Campanella, pp. 7-9.

[32]Ibid., p. 9.

[33]Grabner and Cashman, p. 565.

[34]Interview with Bauer, 4 Nov. 1988.

CHAPTER IV

DEPARTMENT OF DEFENSE'S DEFENSE SATELLITE COMMUNICATIONS SYSTEM

To compare the ACTS with other systems, let us begin by examining the Defense Satellite Communications System. The Defense Satellite Communications System (DSCS) III and the DSCS Follow-On (DSCS F) represent the current technologies of military satellite systems. While the anti-jamming capabilities of these systems is classified and outside the scope of this thesis, the remaining system technologies are unclassified and applicable to our ACTS comparison. These technologies include:

- onboard switch matrix
- multiple-beam antennas (MBAs) with selective coverage patterns
- earth coverage horn (ECH) antennas
- steerable gimbaled-dish antenna (GDA)
- single channel transponder and antenna
- multiple modulation techniques
- 7.75/8.4 GHz and 21.2/45.5 GHz frequency components

Other topics include background/history, spacecraft physical description, earth station antenna characteristics, and susceptibility to atmospheric loss.

Background/History

The DSCS program itself was initiated in 1967 and the DSCS III portion became operational in 1982 with the follow-on spacecraft planned for launch in 1996. DSCS III satellites are designed to have a continuous operating on-orbit mission life of ten years.[1] The DSCS is an integral part of the Global Defense Communications System which was designed to provide vital communications service to the United States and Allied Forces throughout the world by means of satellites. The DSCS III mission also includes the use of an on-board single channel transponder to supplement dedicated Air Force Satellite Communications spacecraft for command and control communications from the National Command Authorities and Commanders to the nuclear and support forces.[2] The DSCS III spacecraft is three-axis stabilized with an on-orbit weight of approximately 2350 pounds.[3] The approximate dimensions and appearance of the fully deployed DSCS III is shown in Figure 8. At this time, while several of the DSCS F technologies have been chosen a drawing of the spacecraft is not available.

Transponder Channels

The DSCS III has six transponder channels each capable of being shared by multiple users (multiplexed signals), and one single channel transponder (SCT) which cannot receive multiplexed signals. Transponders for Channels 1 and 2 have traveling wave

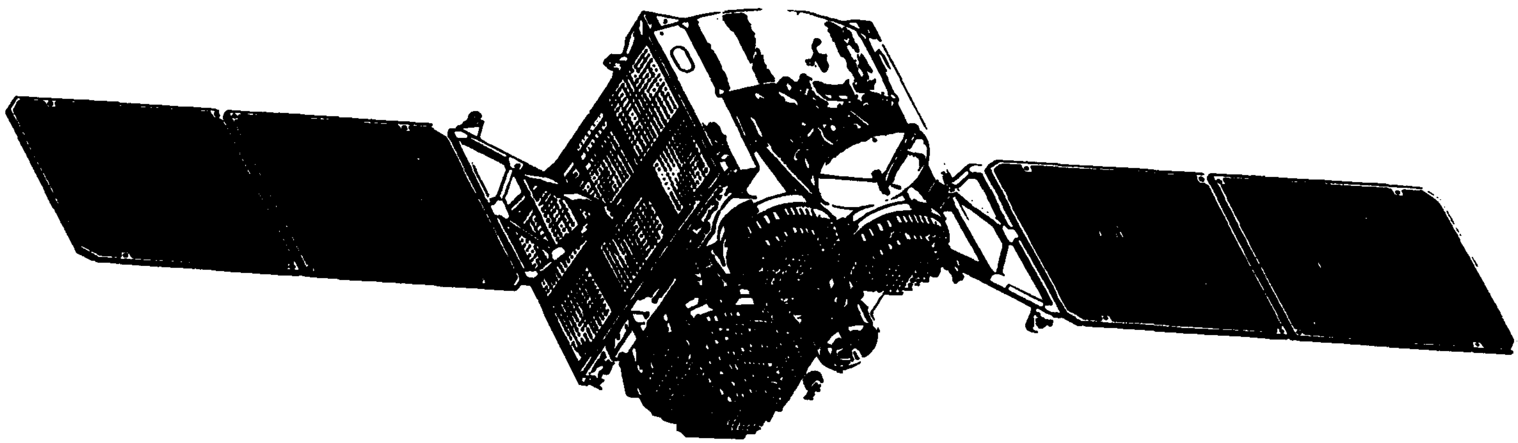

Figure 8. DSCS III Spacecraft.

Source: RCA Aerospace and Defense, DSCS III Secure Satellite Communications (Princeton, New Jersey: Astro-Space Division, n.d.), pp. 3-4.

tube amplifiers (TWTAs) with an output of 40 watts. Transponders for Channels 3-6 have 10 watt TWTAs. Each of the six transponders is capable of relaying Time Division Multiplexed/Frequency Division Multiple Access (TDM/FDMA), Code Division Multiple Access (CDMA), and Time Division Multiple Access (TDMA) signals utilizing Frequency Modulation, Phase Shift Keying (PSK), Quadrature PSK, and Binary PSK modulation techniques.[4] A transponder's high power amplifier must operate in an essentially linear mode when relaying FDMA signals, but operation in a near-saturated mode is permitted for CDMA and TDMA signals.[5] This requires the gain of the transponder to be controllable. Through the use of onboard attenuators controlled from the ground, 10 gain states are available ranging from 89.3 to 135.5 dB depending upon the channel and antenna used as depicted in Table 2.[6] The DSCS III operates at 7.9-8.4 GHz for uplinks and 7.25-7.75 GHz for the downlinks.

Single Channel Transponder

The primary function of the SCT is to provide secure and reliable dissemination of the Emergency Action Messages (EAM) and Single Integrated Operational Plan communications.[7] These communications deal with the activation of nuclear forces during war. The SCT has dedicated UHF receive and transmit antennas as well as the capability of using a receive MBA or ECH antenna and an MBA transmit antenna or the GDA to extend its downlink contact and provide improved ground station signal reception.[8] The UHF

Table 2. DSCS III Transponder Gain Values

	1		2		3		4			5	6
Nom. TWTA P_o	40 W		40 W		10 W		10 W			10 W	10 W
Downlink Ant.	MBA	GDA	MBA	CDA	MBA	EC	MBA	GDA	EC	FC	EC
Gain State 1	135.5	134.8	134.0	133.3	128.7	128.9	129.0	128.5	129.2	128.4	129.8
Gain State 2	131.0	130.3	127.5	126.8	122.0	122.2	123.5	123.0	123.7	124.4	123.3
Gain State 3	125.0	124.3	121.0	120.3	115.2	115.4	117.0	116.5	117.2	117.9	117.3
Gain State 6	120.5	119.8	119.0	118.3	113.7	113.9	114.0	113.5	114.2	113.4	117.3
Gain State 4	118.5	117.8	114.5	113.8	109.0	109.2	111.0	110.5	111.2	111.4	110.3
Gain State 7	116.0	115.3	112.5	111.8	107.0	107.2	108.5	108.0	108.5	109.4	108.3
Gain State 5	112.0	111.3	108.0	107.3	102.7	102.9	104.0	103.5	104.2	104.9	104.3
Gain State 8	110.0	109.3	106.0	105.3	100.2	100.4	102.0	101.5	102.2	102.9	100.8
Gain State 9	103.5	102.8	99.5	98.8	94.0	94.2	96.0	95.5	96.2	96.4	94.3
Gain State 10	97.0	96.3	93.0	92.3	87.7	87.9	89.0	88.5	89.2	89.9	89.3

Source: Defense Communications Agency, <u>DCA Circular 800-70-1, Supplement 2, Satellite Communications Reference Data Handbook</u>, Vol. II, Aug.1984, p. 4-35.

antennas are a bow tie configuration for the receive and a crossed bowtie configuration for the transmit. A block diagram of the SCT is provided in Figure 9. It should be noted that the SCT in fact does process signals it receives rather than merely relay them as do the other six communications channels. When the SCT receives its signal it demodulates it, decodes and authenticates command messages, controls the operational configuration of the SCT transponder, stores a received EAM and repeatedly reads it out from the memory under control of a resettable five-minute timer or by-passes the memory and rebroadcasts any messages received for approximately 15 minutes, generates a UHF as well as SHF carrier that is modulated with message data and amplified, and transmits a downlink via the UHF antenna with the option of simultaneously transmitting via the SHF transmit MBA or GDA.[9]

Antenna Types

The DSCS III spacecraft carries a variety of antenna types including Multiple Beam Antennas (MBAs). The DSCS III utilizes one 61-beam receive MBA and two 19-beam transmit MBAs. The use of these MBAs facilitates selective coverage patterns but does not allow for terminal interconnection by any type of beam hopping.

Each of the MBAs on the DSCS utilizes a single beam forming network (BFN). The DSCS BFN functions electronically the same way the ACTS BFNs do allowing the MBA to form the antenna pattern into different shapes and sizes and point the pattern to

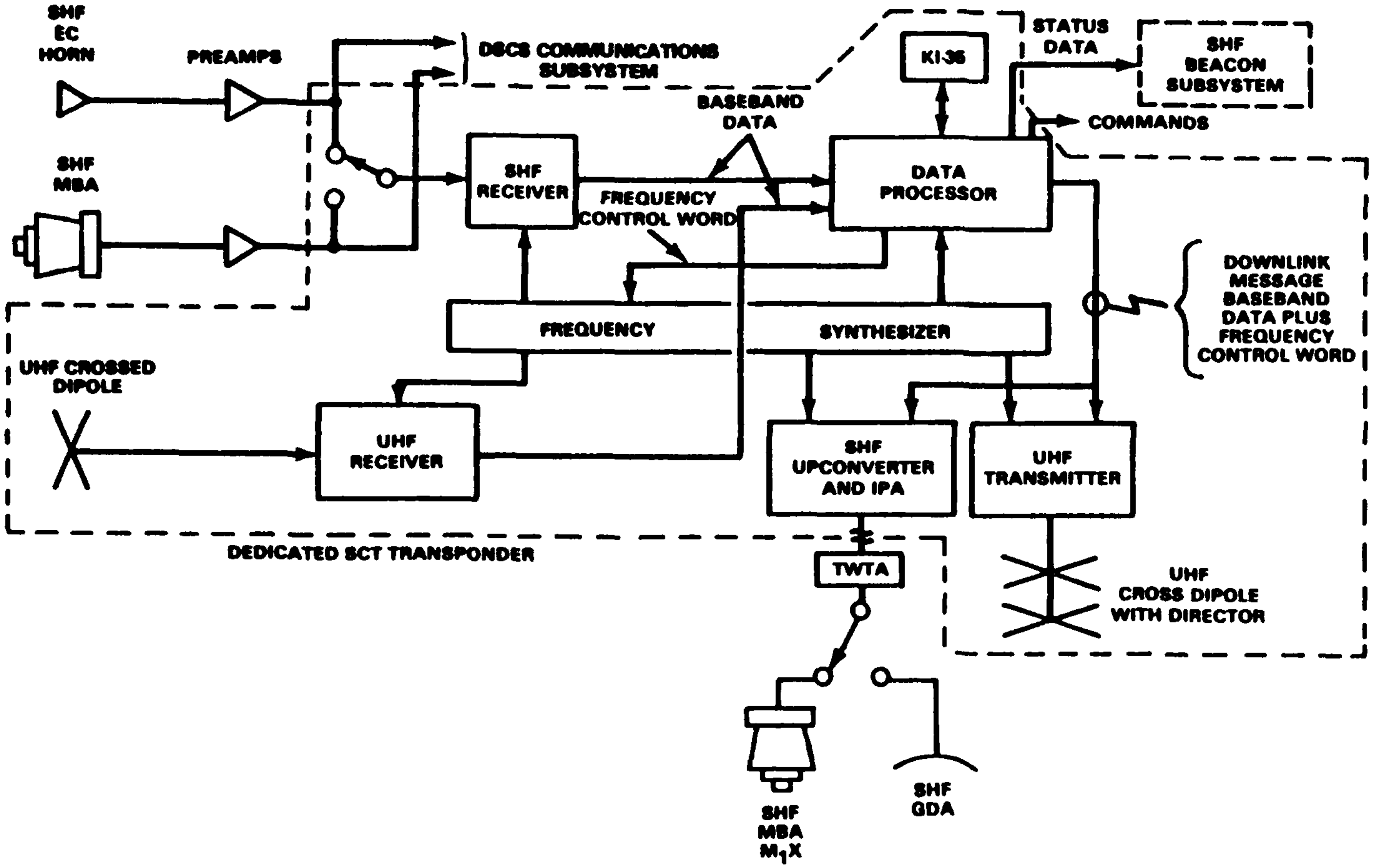

Figure 9. DSCS III Single Channel Transponder Functional Diagram.

Source: Defense Communications Agency, DCA Circular 800-70-1, Supplement 2, Satellite Communications Reference Data Handbook, Vol. II, Aug. 1984, p. 4-36.

desired locations. With only one element of the BFN activated, a spot beam (narrow coverage-NC) is generated with a minimum beamwidth of 1.0 degrees. With all of the BFN elements activated an earth coverage (EC) beam of 19 degrees is generated.[10] In addition to the MBAs and the SCT's UHF antennas, the DSCS carries earth coverage horns and a steerable gimbaled-dish antenna.

There are four earth coverage horns (ECHs) onboard the DSCS III. Two of the ECHs are for receiving (E1R and E2R) and two are for transmitting (E1X and E2X). The uplink ECHs receive right-hand circular polarized signals and the downlink ECHs transmit left-hand circular polarized signals. E1R receives signals at 8.34 - 8.40 GHz while E2R receives signals at 7.90 - 7.95 GHz. E1X transmits at 7.615 - 7.675 GHz and E2X at 7.70 - 7.75 GHz.[11] This frequency diversity between each of the transmit and receive antennas enables them to maintain the same coverage patterns without interferring with each other.

The gimbaled-dish antenna (GDA) is the last of the antenna types onboard the DSCS III for communications purposes. The GDA is a steerable parabolic downlink antenna which provides a narrow beam (approximately 3 degrees) over a + or - 10 degree cone of coverage around the subsatellite point.[12] The subsatellite point is where a line drawn from the satellite to the center of the Earth intersects the Earth's surface. The steering of the GDA is controlled by ground commands and the gain of the GDA is 30.8 dB for a 1.5 degree circle.[13] A summary of EIRPs from the previously described downlink antennas is provided in Table 3.

Onboard Switch Matrix

The signals received and transmitted by DSCS III are routed through an onboard switch matrix in a somewhat flexible manner to the different antennas according to a given plan. Two of the low power channels (Channels 5 and 6) are dedicated to the ECHs for reception and transmission. Channels 1-4 (two high power and two low power channels) can be commanded from the ground to connect to either of the receive ECHs or the receive MBA. For transmission, Channels 1 and 2 (high power) are connected to the transmit MBAs or to the GDA. Channels 3 and 4 (low power) can be connected to a transmit ECH or share a transmit MBA with a high power channel. Channel 4 can also be switched to the GDA. Figure 10 depicts the transponder channel and antenna connectivity described above. It should be noted that while different switching states are available on the DSCS III, they are not dynamically switchable in the sense that separate earth stations' transmissions are routed or switched on an individual basis at the satellite. A particular switch state (transmission route) for a given channel is established onboard the satellite by ground control. All communications initiated on that channel will follow the same established route. DSCS program managers would like a system like the ACTS OSBS/TDMA BBP, but feel it is too complex and

Table 3. DSCS III Downlink Antennas, EIRP dBW.

Channel	ECH	GDA	MBA (EC)	MBA (NC)
1	-	44	29	40
2	-	44	29	40
3	25	-	23	34
4	25	37.5	23	34
5	25	-	-	-
6	25	-	-	-

Source: Defense Communications Aency, DCA Circular 800-70-1, Supplement 2, Satellite Communications Reference Data Handbook, Vol. II, Aug. 1984, p. 4-43.

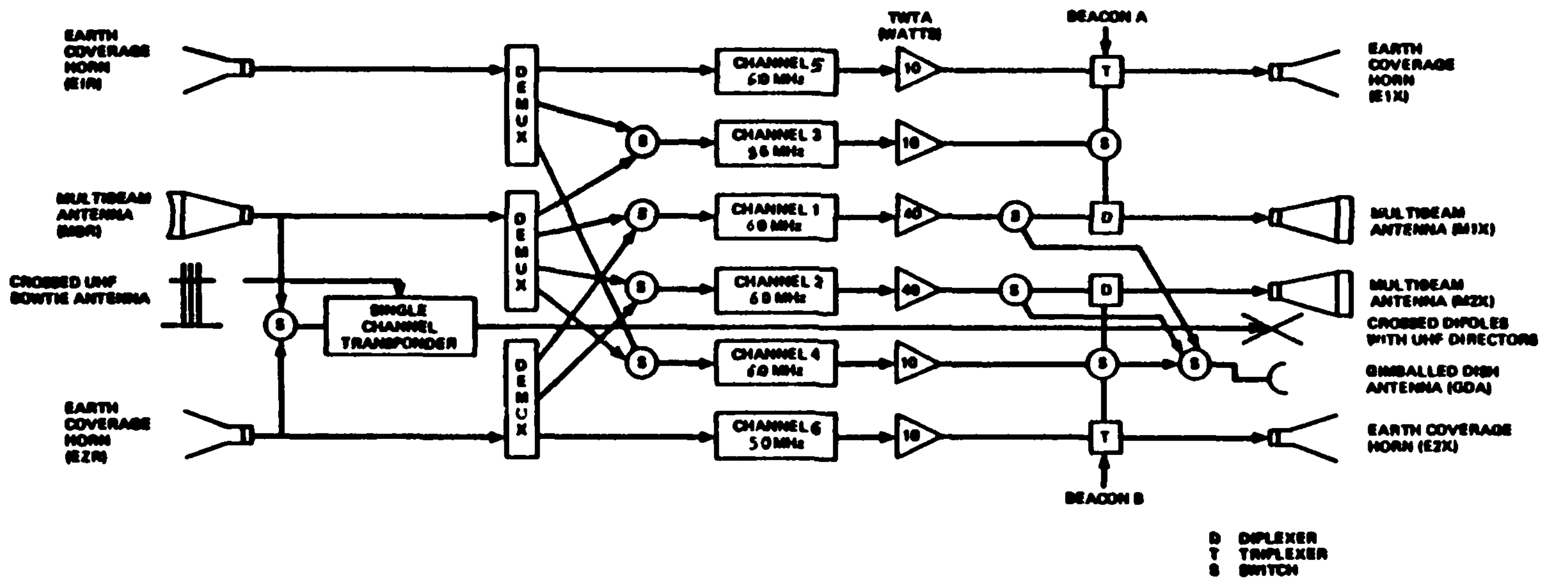

Figure 10. DSCS III Transponder Channel and Antenna Connectivity Diagram.

Source: Defense Communications Agency, DCA Circular 800-70-1, Supplement 2, Satellite Communications Reference Data Handbook, Vol. II, Aug. 1984, p. 4-45.

difficult to accomplish.[15] Each of the antenna systems aboard the DSCS are controlled by a ground facility called the DSCS Operations Control System.

The DSCS Operations Control System (DOCS) is a near real time control system that functions on a largely computerized basis. It continuously monitors link performance at each terminal and at the satellite to provide information for developing corrective actions to alleviate system degradation and accommodate changing user requirements. Corrections or changes must, however, be implemented manually by DOCS operators. The DOCS performs these functions using an order-wire system similar to that of the ACTS.[16]

Earth Stations

Earth stations for the DSCS III cover a large variety of sizes and configurations. This variety includes fixed mobile systems that can be airborne, land based, or ship based. For our purposes we will examine the extremes of this variety covering the largest and smallest earth stations available to gain an understanding of the upper and lower limits of the stations available. The AN/FSC-78 Heavy Terminal is the largest earth station and is a fixed land based system. On the other end of the spectrum is the AN/ASC-24 Airborne Terminal which is obviously mobile.

The AN/FSC-78 Heavy Terminal (HT) is a fixed satellite communications terminal used as a major nodal communications center on a worldwide basis.[17] The antenna itself uses a cassegrain feed system with a 60-ft. main parabolic reflector, a 7-ft. subreflector, and a five-horn feed system with a total terminal weight of 425,000 pounds.[18] The G/T of the receiver subsystem is 39 dB/degrees Kelvin with an EIRP of the dual mode transmitter subsystem of either +124 dBm (94 dBW) or +127 dBm (97 dBW).[19]

The AN/ASC-24 Airborne Terminal is a SHF terminal used on the National Emergency Airborne Command Post. The antenna subsystem uses a lightweight 33-in. parabolic reflector with a cassegrain-type feed and a 6-in. hyperbolic subreflector mounted inside with a low loss radome.[20] The gain of the antenna is 32 dB with a G/T of 6.8 dB/degrees Kelvin and an EIRP of 72 dBW.

DSCS Follow-On EHF Operation

One of the main enhancements for the DSCS Follow-On (DSCS F) is its operation at EHF. Specifically the DSCS F will receive at 43.5 - 45.5 GHz and transmit at 20.2 - 21.2 GHz.[21] Operation at this higher frequency will allow more bandwidth, higher bit transmission rates, and smaller earth stations over the DSCS III. The largest channel capacity available on the DSCS III is approximately 115.6 Mbps compared with a value of 320 Mbps for the DSCS F verifies higher bit rate transmissions.[22] The fact that the DSCS F utilizes a maximum antenna size of 20 ft. (EIRP = 97 dBW, G/T = 31 dB/degrees Kelvin) for its earth stations in comparison with 60 ft. for the DSCS III both at a BER of 10 E-5 or less verifies the smaller antenna size needed.[23] The DSCS F satellite's ability to transmit with an EIRP of 52 dBW for spot coverage[24] compared with the DSCS III's transmit EIRP of 37.3 dBW would also allow for smaller earth station antennas.[25]

Rain Fade

The downside to the EHF frequencies utilized by the DSCS F is increased susceptibility to rain fade over the DSCS III. The DSCS III has a fixed link margin of 4 dB on the receive link and 2 dB on the transmit link. The margin remains constant because variations in antenna sizes and EIRP affect data throughput, not the margin.[26] The DSCS F has variable link margins of 0-6 dB for the transmit link and 0-16 dB for the receive link.[27] The variable margins in this instance are attributable to larger antennas and EIRPs as well as variations in data throughput.[28] It can be seen in the calculations from the Appendix that while the maximum attenuations suffered by the DSCS III for 0.1 percent of the year in Tampa are: receive = 2.5 dB, transmit = 2.95 dB. The DSCS F suffers: receive = 71 dB, transmit = 20.8 dB. It should be noted that even though the DSCS F figures are much higher, even the DSCS III receive value of 2.5 dB is 0.5 dB more than the allowed link margin. This would allow an availability rate for an earth station in Tampa, Florida of 99 percent for transmitting data and 99.9 for receiving data. The only alternative for attempting to increase these rates is to manually decrease the bit transmission rates.[29]

NOTES--CHAPTER IV

[1]Defense Communications Agency, DCA Circular 800-70-1, Supplment 2, Satellite Communications Reference Data Handbook, Vol. II, Aug. 1984, p. 4-15.

[2]Ibid., p. 1-3.

[3]Ibid., p. 1-4.

[4]Ibid., pp. 5-43, 5-66, 5-70.

[5]Ibid., p. 4-33.

[6]Ibid.

[7]Ibid., p. 4-34.

[8]Ibid.

[9]Ibid., pp. 4-37, 4-38.

[10]Ibid., p. 4-41.

[11]Ibid., p. 4-40.

[12]Ibid., p. 4-42.

[13]Ibid.

[14]Ibid., p. 4-30.

[15]Telephone interview with Steve Boyle, DSCS Program Management Office, USAF Space Division, 7 Nov. 1988.

[16]Agency, p. 8-7.

[17]Ibid., p. 5-1.

[18]Ibid., pp. 5-1, 5-4.

[19]Ibid., p. 5-5.

[20]Ibid., p. 5-55.

[21]USAF Space Division, "EHF Payload for DSCS Follow-On Study," RFP F 04701-87-R-0031, Appendix 13, Annex B, Atch 1, USAF Space Division, n.d., p. 1.

[22]Telephone interview with Rich Williams, Defense Communications Agency, 14 Nov. 1988.

[23]Space Division, pp. 1-3.

[24]Ibid., p. 4.

[25]Agency, p. 4-35.

[26]Interview with Williams, 14 Nov. 1988.

[27]Space Division, p. 1.

[28] Interview with Williams, 14 Nov. 1988.

[29] Interview with Boyle, 7 Nov. 1988.

CHAPTER V

INTERNATIONAL TELECOMMUNICATIONS SATELLITE ORGANIZATION'S INTELSAT V AND VI

The satellites of the International Telecommunications Satellite Organization (INTELSAT) represent the current and near-future technologies available to the commercial sector. INTELSAT is currently contracting for the Intelsat VII which is scheduled for launch in January of 1992. While this represents their most current system it incorporates no new satellite technologies with the exception of increased power output and is not used in this thesis for comparison with the ACTS. The satellites Intelsat V and VI represent the following communications technologies which will be used in comparison with NASA's ACTS:

- frequency components at 6/4 GHz and 14/11 GHz
- frequency reuse
- array-fed offset reflector antennas
- multi-band communications
- static switch matrices
- satellite switched time division multiple access (SS/TDMA)

Other topics include background/history, spacecraft physical description, earth station characteristics, and signal susceptibility to atmospheric loss.

Background/History

INTELSAT is an international organization of 114 countries that owns and operates the global communications satellite system serving the entire world. It is a commercial non-profit cooperative that was created in 1964 and today controls a network of 13 satellites in geosynchronous orbit providing communications to more than 700 antennas.[1] Intelsat V (and its upgrade version V-A) is an operational satellite with several functioning in geosynchronous orbits at this time. It has a capacity of 12,000-15,000 voice circuits and two television channels.[2] The weight of the Intelsat V at launch is 4,110 pounds with a width of 22.25 ft., height of 21 ft., and a solar array length of 52 ft. end to end.[3] The appearance of the Intelsat V is shown in Figure 11. The Intelsat VI is a spin-stabilized satellite planned for launch in 1989 with four more on order and is the source of INTELSAT's SS/TDMA capability. It has a capacity of 120,000 voice circuits and three television channels.[4] The appearance and dimensions of the satellite are shown in Figure 12.

Multi-Band Communications and Frequency Reuse

Both the Intelsat V and VI operate with multi-band communications and frequency reuse. Multi-band communications means that the satellite operates in more than one frequency band for relaying communications signals. The Intelsat V and VI

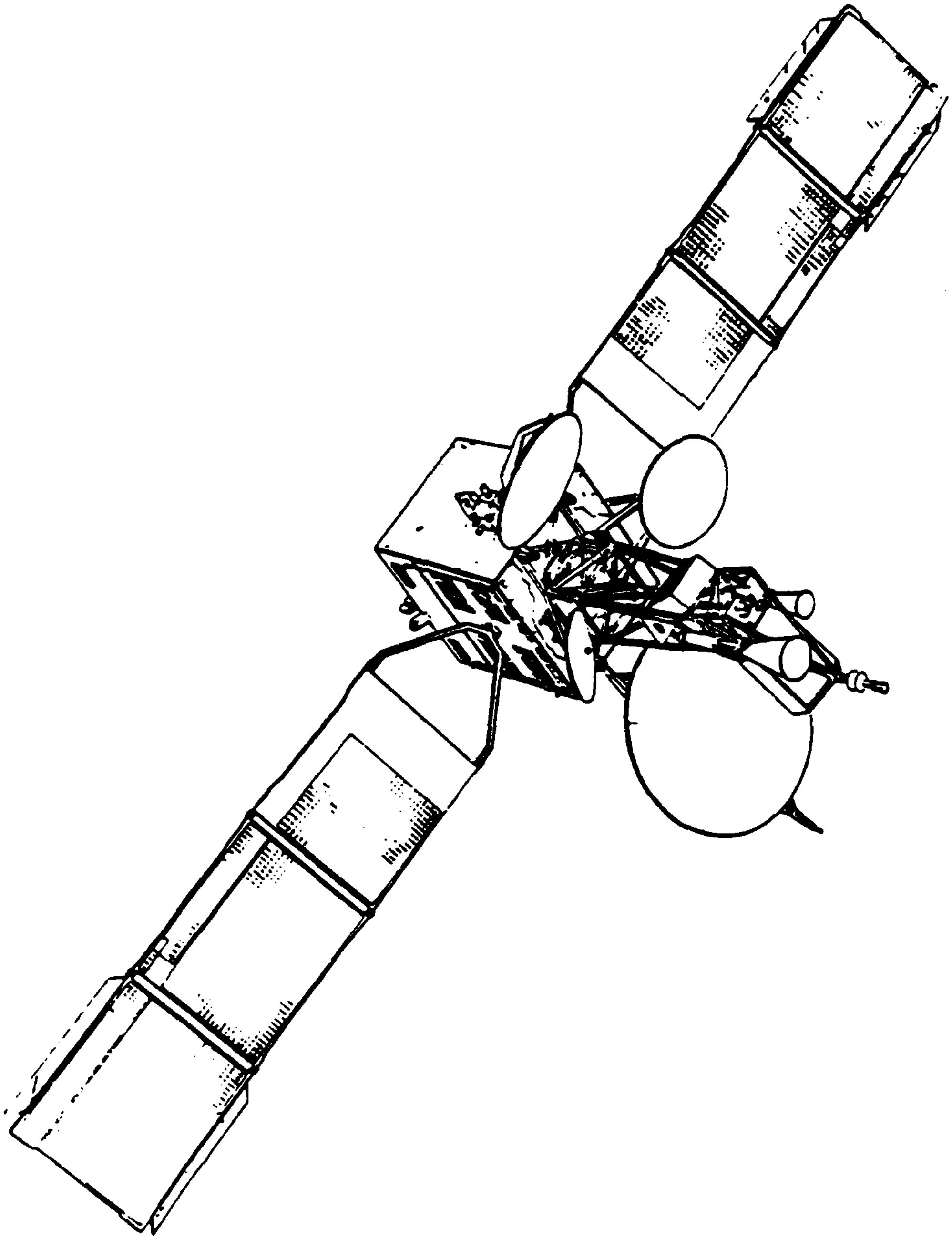

Figure 11. Intelsat V Spacecraft.

Source: Ford Aerospace, INTELSAT V BACKGROUNDr INFORMATION (Palo Alto, California: Ford Aerospace, n.d.), p. 1.

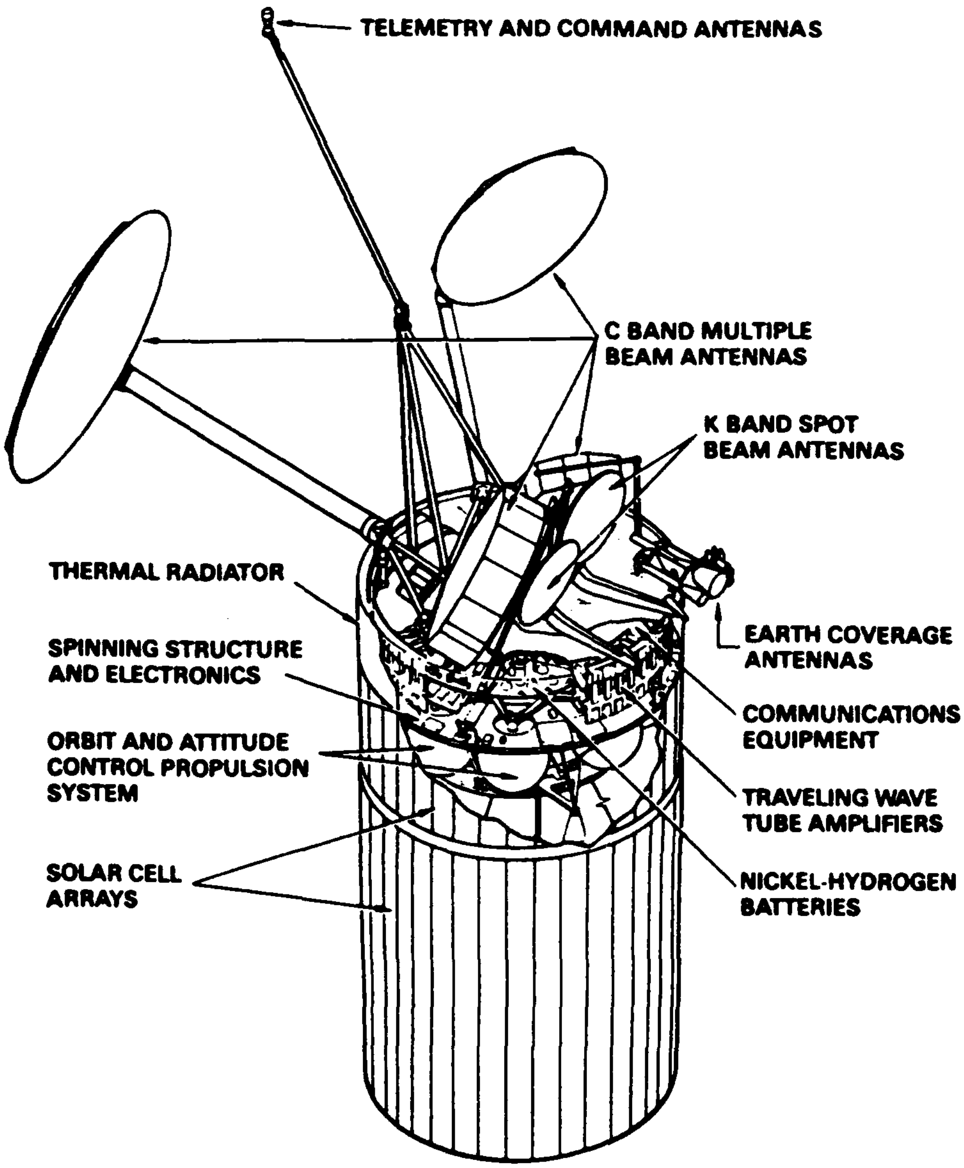

Figure 12. Intelsat VI Spacecraft.

Source: Hughes Aircraft Company, Intelsat VI Fact Sheet (El Segundo, California: Public Relations Department, Space and Communications Group, n.d.), p. 2.

operate at both the C (6/4 GHz) and K (14/11 GHz) bands. Most of the channels on each of the satellites have the capability of being switched from C to K or K to C band within the satellite. Frequency reuse for the satellites is achieved at the C band by using both orthogonal polarization and spatial beam isolation techniques to provide a four-fold reuse of the available bandwidth.[5] This is done by projecting a hemispheric beam pattern with a zone beam pattern inside it, both share the same frequency but are polarized in opposite directions (orthogonal polarization). A second pair of hemi/zone beams are used by the satellite, but they are pointed to a different (non-overlapping) geographic location than the first set and thus are separated spatially. This polarization and spatial separation prevents interference between the beams and results in the same frequency being used four times. Frequency reuse through orthogonal spatial separation is also used in the K band for the satellites.[6]

Array-Fed Offset Reflector Antennas

The array-fed offset reflector antennas utilized by the Intelsat V and VI operate at 6/4 GHz and are essentially multiple beam antennas (MBAs). Both MBAs provide hemi/zone coverage and function electrically in the same manner as those of the ACTS and DSCS. The Intelsat V has a transmit MBA reflector of 8-ft. diameter with an 88-element feed array.[7] The Intelsat VI has a transmit reflector diameter of 10.7 ft. with a 149-element feed array.[8] The Intelsat V MBA allows pointing to different areas once the satellite is in orbit but does not provide for any type of beam hopping. The MBAs are usually used to establish the proper antenna pattern for the land masses under a particular satellite's coverage. This is needed since different Intelsat Vs will be stationed in different orbits in order to provide complete global coverage. This beam shaping is also used to concentrate power into the desired coverage areas increasing EIRP.[9] The Intelsat VI MBA provides the same functions. Intelsats V and VI also utilize mechanically steerable 5-degree spot beam antennas operating at 11/14 GHz and global coverage antennas at 4/6 GHz.

Static Switch Matrices

The static switch matrices are used by both the Intelsat V and VI to provide interconnectivity between most of the antenna beams on each satellite. The only beam not connectable to the other beams is the global antenna of the Intelsat VI.[10] Block diagrams are provided in Figures 13 and 14 to show the interconnectivity which can be provided by each system. Intelsat V contains 26 repeaters: 16 hemi/zone (C-band), 4 global (C-band), and 6 spot (K-band). Intelsat VI contains 48 repeaters: 38 C-band (divided between hemi/zone and global) and 10 K-band (spot).[11]

The static switch matrices are essentially ground controlled switches onboard the satellite that are used for initial

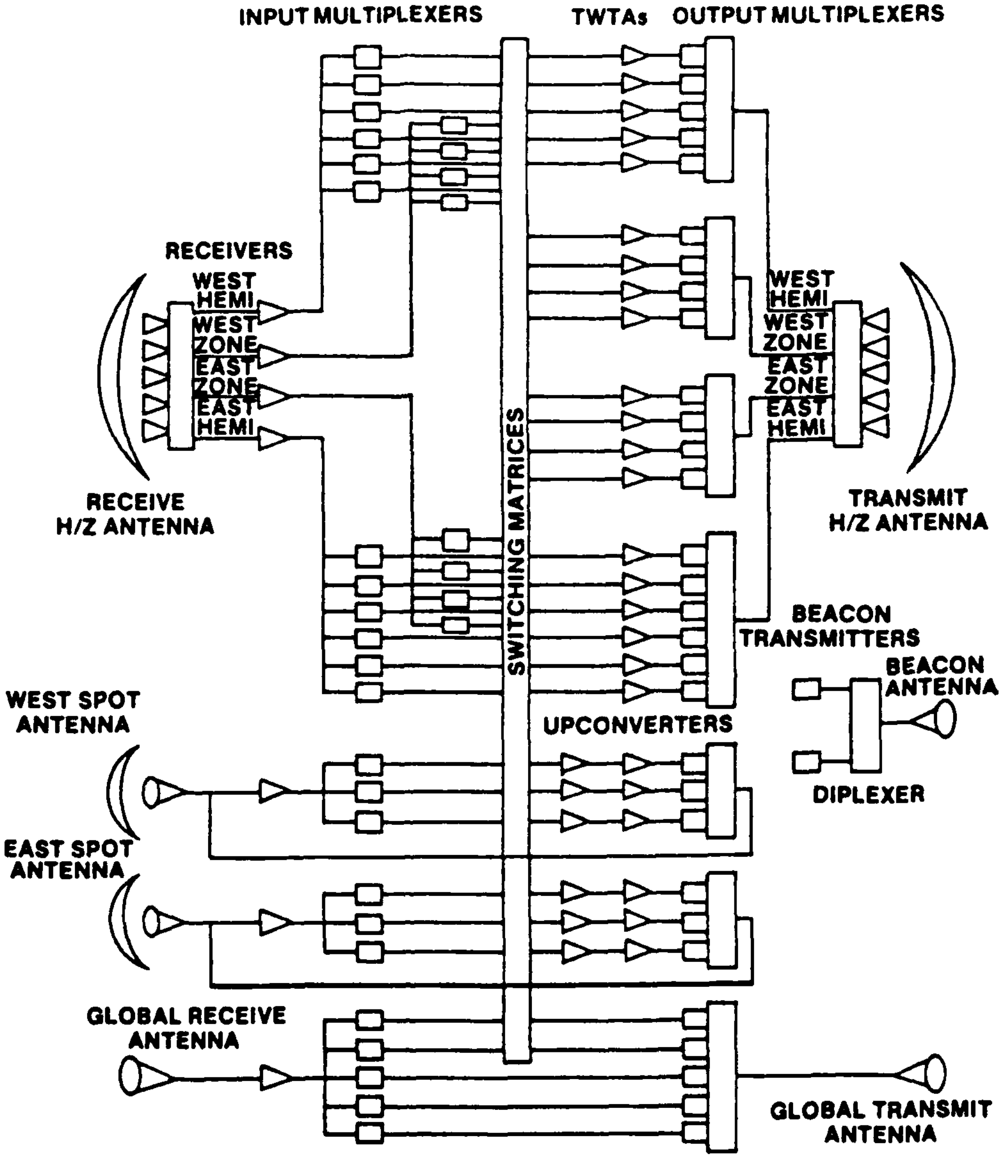

Figure 13. Intelsat V Commmunications Payload Block Diagram.

Source: John T. Neer and Christopher F. Hoeber, "Intelsat V System Summary and Initial Launch Operations," Microwave Journal, Jan. 1982, p. 58.

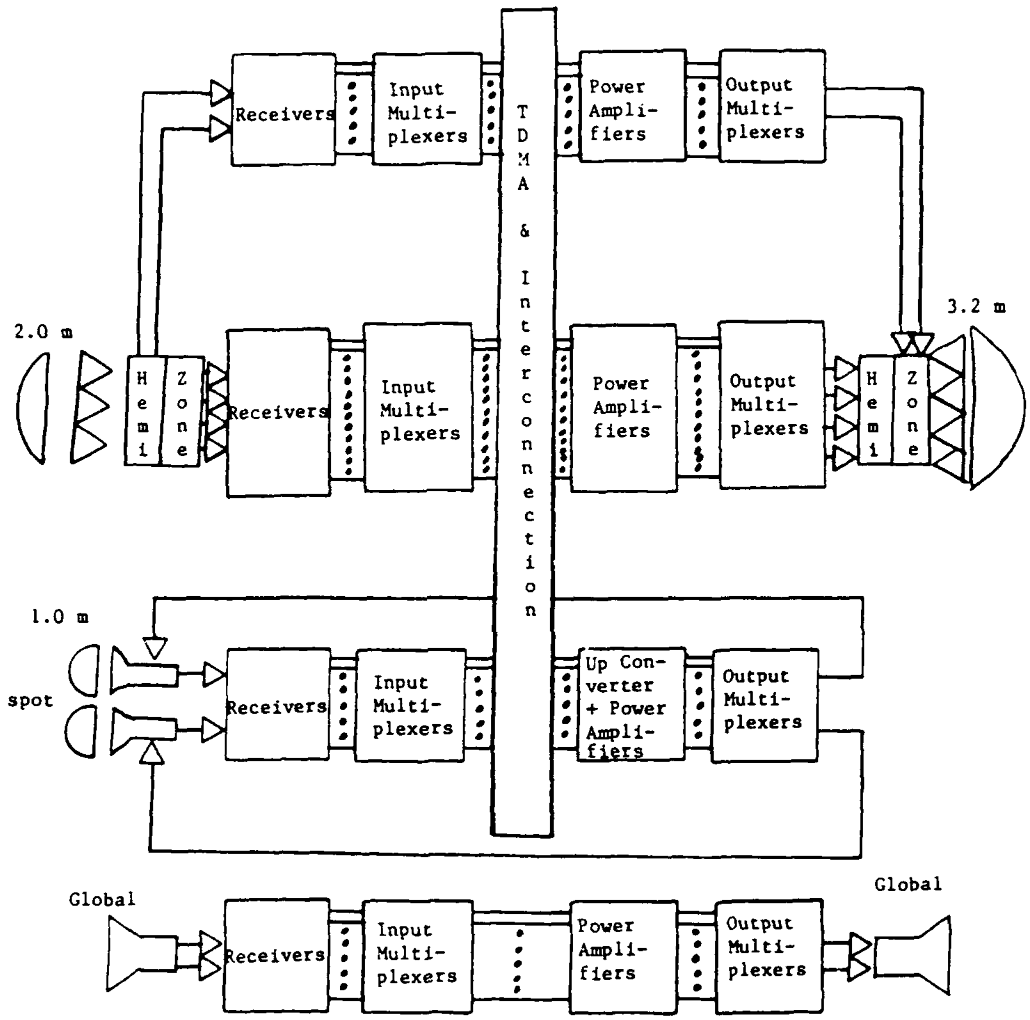

Figure 14. Intelsat VI Communications Payload Block Diagram.

Source: Hughes Aircraft Company, INTELSAT VI (El Segundo, California: Space and Communications Group, n.d.), p. 6.

configurations and changes as needed. The switch matrix is considered static because paths are established by ground control on a channel-by-channel basis. This means that all transmissions on a given channel must follow the same route. This continues until users go through a formal request procedure to have their channel routes changed. If INTELSAT can accommodate the change (after reviewing other user requirements) the change will be made. From the user's point of view the static-switch matrix can essentially be considered a fixed route.

Satellite Switched Time Division Multiple Access

Satellite Switched Time Division Multiple Access (SS/TDMA) is provided by Intelsat VI and is far more dynamic than static switching. The operation of SS/TDMA was described and depicted in the ACTS Microwave Switch Matrix section of Chapter III and will not be repeated here. Not all channels on the Intelsat VI can utilize the SS/TDMA. Only Channels 1-2 and 3-4 are connected to dynamic switches to provide SS/TDMA operation.[12] The microwave switch used by the SS/TDMA hops (provides interconnection) between six coverage regions. So far this system has only been requested by the more wealthy members of INTELSAT, because of the cost. While expensive, the SS/TDMA does provide much more connectivity than the static switch matrix.[13] Hughes Aircraft Company (the manufacturer) claims this as a "major new technology sponsored by INTELSAT."[14]

Earth Stations

The earth station antennas used by Intelsats V and VI cover a large variety. The size of antennas ranges from 56.7 ft. to 2.7 ft. Intelsat provides specific guidelines for technical performance and earth station owners can choose their own performance within the set parameters.[15] BER and path link margins that can be expected with the Intelsat system are: BER 10E-8, 14 GHz uplink 2.5 dB, 11 GHz downlink 3.5 dB.[16] These margins are provided for IBS which stands for Intelsat Business Service, a digital service offering for voice, data, text, facsimile, and video conferencing.[17] Another example of performance considerations in the 6/4 GHz band include EIRPs of 26.8 to 33.4 dBW and G/Ts of -5.3 to -12.1 dB/K for the Intelsat V.[18] The last item to be considered is that of atmospheric losses particularly those loses due to rain fading for the operational frequencies.

Rain Fade

As with other satellite systems, the rain fade attenuation calculations in the Appendix provide the amount of attentuation that can be expected for the 14/11 GHz frequencies utilized by Intelsats V and VI. From the results we can see the 14/11 GHz band is more strongly attenuated in comparison with the lower frequencies. The 6/4 GHz band is not calculated due to the minimum effects of rain fade at these frequencies.

NOTES--CHAPTER V

[1]INTELSAT, INTELSAT, The Global Telecommunications Cooperative (Washington, D.C.: INTELSAT, 1987), pp. 1, 11.

[2]Ibid., p. 5.

[3]Ford Aerospace, INTELSAT V BACKGROUND INFORMATION (Palo Alto, California: Ford Aerospace, n.d.), p. 2.

[4]INTELSAT, Cooperative, p. 5.

[5]J. Binckes, INTERNATIONAL SATELLITE COMMUNICATIONS SERVICES FOR THE PACIFIC OCEAN BASIN IN THE PAST, PRESENT AND FUTURE--INTELSAT VII--ERAS (Washington, D.C.: Communications Satellite Corporation, 1988), p. 10.

[6]Ibid.

[7]G. H. Schennum and H. T. Ward, INTELSAT V SPACECRAFT ANTENNA SUBSYSTEM (Palo Alto, California: Ford Aerospace and Communications Corporation, Western Development Laboratories Division, n.d.), pp. 2-3.

[8]Hughes Aircraft Company, INTELSAT VI (El Segundo, California: Space and Communications Group, n.d.), p. 5.

[9]Binckes, PAST, PRESENT AND FUTURE, p. 7.

[10]Hughes, INTELSAT VI, p. 7.

[11]Binckes, PAST, PRESENT AND FUTURE, p. 10.

[12]Hughes, INTELSAT VI, p. 7.

[13]Telephone interview with J. Binckes, Principal Engineer, Communications Satellite Corporation, 14 Nov. 1988.

[14]Hughes, INTELSAT VI, p. 2.

[15]INTELSAT Cooperative, p. 8.

[16]INTELSAT, INTELSAT EARTH STATION STANDARDS (IEES) (Washington, D.C.: INTELSAT, Dec. 1987), No. 309, pp. 1, 33.

[17]INTELSAT, INTELSAT Report 1987-88 (Washington, D.C.: INTELSAT, March 1988), p. 21.

[18]John T. Neer and Christopher F. Hoeber, "Intelsat V System Summary and Initial Launch Operations," Microwave Journal, Jan. 1982, p. 58.

CHAPTER VI

COMPARISONS AND CONCLUSIONS

In examining the ACTS and comparing it with the DSCS and Intelsat systems, it becomes obvious that the ACTS will not be able to achieve completely all of its goals (rain fade compensation) and may be verifying technologies (MBAs and SS/TDMA) already proven by the other systems. Does this mean the ACTS will not provide benefits to the military or commercial sectors? Does this mean NASA's ACTS is not a desirable undertaking? The author believes the ACTS is desirable and will benefit the military and civilian sectors.

Ancillary Technologies

Mechanically Steerable Antenna

First to be compared are the ancillary technologies of the stems such as mechanically steerable antennas, modulation techniques, and earth station antenna characteristics. The steerable gimbaled-dish antenna (GDA) of the ACTS functions essentially the same as the GDA of DSCS III. So, while this may be a useful means of tracking the space shuttle for ACTS it represents no new innovations. This is probably why NASA did not identify this as one of the ACTS key technologies.

Modulation Techniques

In the area of modulation techniques that ACTS' use of Serial Minimum Shift Keying (SMSK) does seem to represent a new approach. Even the DSCS system with its ability to utilize a variety of modulation techniques does not have SMSK in its repertoire. While these techniques seem to serve the DSCS III well, SMSK may be a good choice for the DSCS F. With the severe rain fading at the high frequencies, a more power-efficient modulation like SMSK might aid in better using the available power to overcome the fade at the expense of some of the bandwidth. Since INTELSAT is concerned about increasing power availability for the Intelsat VII and has achieved increased bandwidth through frequency reuse, SMSK may also be an option to be explored for this system.

Earth Stations

The area of comparison between earth station characteristics is highly dependent upon numerous variables including bit transmission rates and EIRP values. Basically the user is able to choose a particular parameter such as bit rate, bit error rate, antenna size, or antenna power and build the rest of the system around it to achieve the necessary link margins for successful communications. It does seem, however, that the ACTS with a maximum antenna size of 10.7 ft. generally operates with smaller antenna sizes than the DSCS and Intelsat systems while still maintaining good link margins and data rates. This is partly attributable to the ACTS' high transmission EIRP values from the narrowly concentrated spot beams and its use of the 20/30 GHz band. So in this area while all of the systems are capable of effective operation the ACTS does seem to provide advantages over the others.

Single Channel Transponder

The Single Channel Transponder (SCT) aboard the DSCS III is a highly specialized feature but it does represent an onboard capability to process communications transmissions. Possibly the ACTS' ability to process communications transmissions from multiple channels will make onboard processing for military systems common.

Primary Technologies

The next comparisons are those of the primary technologies being verified by the ACTS: baseband processing, microwave switch matrix, multiple beam antenna, Ka-band (20/30 GHz) components, and rain fade compensation. It is in these areas that the real advancements and benefits of the ACTS are seen.

Baseband Processor

The ACTS baseband processor (BBP) operating in the onboard stored baseband switched time division multiple access (OSBS/TDMA) mode has no rivals within the comparison systems. The benefits available from OSBS/TDMA are numerous. The fact that noise from the uplink is eliminated prior to downlink transmission provides for a better overall carrier to noise ratio (C/N). The better C/N can be used to reduce the bit error rate (BER), increase bit transmission rates, reduce antenna sizes, or provide for extra link margin over systems without BBP. OSBS/TDMA also allows for less earth station overhead when compared to SS/TDMA. This is because the terminal operating in OSBS/TDMA transmits all of its traffic in one uplink burst and the satellite takes care of downlink routing. For SS/TDMA the terminals have to time traffic bursts with different destinations to arrive at the satellite at the proper time when the switch is in the position of the desired downlink route. When using forward error correction (FEC) or data rate reduction techniques to overcome rain fading, the OSBS/TDMA allows only the portion of the link being attenuated (up, down, or both) to be rate reduced or FEC coded. This allows corrective measures to be implemented only where needed and not burden the entire system due to short-falls on one portion of the link. The switching intelligence in the satellite would also allow very small aperture terminal (VSAT) networks to be interconnected in a mesh topology. The terminals would be able to establish communications paths directly with each other instead of having to route through a central earth station hub. This cuts the transmission delay in half making voice communications much more pleasant.

The possible drawback to the OSBS/TDMA is the complexity onboard the satellites, if the BBP were to fail, all communications through this mode of operation would stop and in a 22,300 mile geosynchronous orbit repair would not be possible. Failure, however, has always been a potential problem for satellite communications but with proper testing and manufacturing methods the majority of satellites are able to out live their projected lives. The satellite industry's track record for reliability once systems achieve their proper orbits and become operational leaves little concern for failure.

Overall the ACTS OSBS/TDMA capabilities will have to be considered a success in new technology and benefit. This is especially true in light of the statement made by Air Force contract personnel that would like to incorporate this technology into the DSCS Follow-On, but feel it is too complex to be accomplished. NASA's efforts will certainly help lead the way in this endeavor.

Microwave Switch Matrix

The ACTS microwave switch matrix (MSM) providing satellite switched time division multiple access (SS/TDMA) allows much more flexibility and a better channel fill rate than static switching but may not be in a technological leadership position. The static switching of the Intelsat V and VI present no real advantages to the users. It provides a means of route reconfiguration for INTELSAT which attempts to satisfy user requests based on availability of circuits and transmission routes. From a user standpoint once a route is established it is essentially permanent with formal requests and applications being required to alter it.

The static switch matrices of the DSCS III and Follow-On provide more flexibility than the INTELSAT systems. They allow path routes to be altered with a near real time orderwire system. A terminal can request a route change and if approved by the ground control station the new route will be implemented. Typically preplanned established routes are used, but when the need arises routes can be altered quickly to meet user needs.

The Intelsat VI's satellite switched time division multiple access (SS/TDMA) onboard switching capability represents a real challenge to NASA's leadership in this area. The INTELSAT SS/TDMA itself functions in a similar manner to NASA's. As a matter of fact, the Intelsat VI SS/TDMA is designed to interconnect six coverage regions whereas the ACTS SS/TDMA only interconnects three. With the Intelsat VI scheduled for launch in 1989 and the ACTS in 1992, it appears that INTELSAT will be verifying the technology of SS/TDMA microwave switch matrices rather than NASA.

It seems plausible that at some point in time NASA should have realized INTELSAT, through Hughes Aircraft Company, would achieve this technology three years ahead of the ACTS. This might have allowed NASA to delete the SS/TDMA MSM and use the funding for a more innovative technology such as the deleted laser intersatellite links.

Multiple Beam Antennas

The technology of multiple beam antennas (MBAs) is prevalent in the comparison systems, but the ACTS use of electrically hopping narrow spot beams is unique. The frequency reuse, increased EIRP, and flexible interconnectivity should provide a positive effect on satellite communications. With finite bandwidth available to satellites, frequency reuse provides a multiplication of the resource. The Intelsat systems also provide for frequency reuse but only through fixed beams.

Increased EIRPs have also been achieved by both the Intelsat satellites and the DSCS III through narrow patterned beams. The ACTS, however, has achieved the highest EIRPs with the narrowest beams. While this represents a technical achievement for the ACTS and the satellite industry as a whole, it should be kept in mind that the other systems have global coverage responsibilities and the ACTS does not. The ACTS system should provide positive benefits to domestic satellite services.

The dynamic flexibility of interconnection provided by the MBAs' hopping spot beams seems to be most beneficial when combined with the other technologies of OSBS/TDMA, VSATs, and the 30/20 GHz frequency band. The reason for this stated combination is because interconnection is probably most easily facilitated with large earth stations and global coverage horns on a satellite. As the demand for VSAT usage and mesh interconnectivity increases so does the need for higher EIRPs provided for in part by narrow spot beams and higher frequencies. The mesh interconnectivity among narrow spot beams is facilitated by systems such as OSBS/TDMA. The point being that some of these technical innovations are only worthwhile when used in conjunction with other technical innovations.

30/20 GHz Components

The ACTS 30/20 GHz band components offer some definite advantages to the satellite industry. Mainly, the increased frequency allows wider bandwidths and smaller antenna sizes through increased gain. The DSCS Follow On is also attempting to reap the benefits of higher frequencies at the 45/20 GHz band. Since this project is not planned for launch until 1996, it may be able to directly benefit from NASA's efforts with the use of higher frequencies. As previously discussed, however, there appear to be real problems with rain fades at these higher frequencies.

Rain Fade

In the area of rain fading all of the systems are susceptible, the higher frequency systems more so than the others. Fade attenuations of A(0.01%) of 110 dB and 184 dB for the ACTS and DSCS F will be very hard to overcome because of their magnitude. In the more arid climates like Denver, the ACTS is able to achieve better availability rates than the higher frequency DSCS F. While the ACTS is not able to completely compensate for all fades, it does have a dynamic system to combat fades where they occur. Since the ACTS is an experimental system with an extensive opertional analysis period ahead of it, it should not be expected to already be perfect. The data gathered from three years of actual experimentation, much of it centered on rain fade attenuations, is sure to provide new solutions and system adjustments to further increase high frequency satellites' immunity to rain fade. Considering that systems like the DSCS F rely on large full-time link margins and possibly manual earth station rate reductions to burn through rain, the ACTS' ability to automate fade detection and compensation on an as-needed basis seems a step in the right direction.

Conclusion

With the needs and desires of the satellite industry pushing into the higher communications frequency bands, the ACTS provides needed technologies to allow NASA to achieve its goal. While the ACTS SS/TDMA MSM does not seem to add greatly to these technologies due to the progress of other institutions, the OSBS/TDMA BBP, MBA with electrically hopping narrow spot beams, SMSK modulation, and Ka-band components with automatic rain fade compensation technologies provide beneficial and desirable innovations to both the military and commercial sectors of the United States.

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APPENDIX

RAIN FADE ATTENUATIONS

Summary[1]

Tampa, Florida

Satellite System	FREQ GHz	Attenuation in dB A(1.0%)	A(0.1%)	A(0.01%)	Margin (dB)	Avail.
DSCS F	45.5	13.9	71.0	184.0	16/13	99.9/99
DSCS F	21.2	3.0	20.8	60.1	6/4	99.9/99.9
ACTS	30.0	6.2	38.6	110.3	16.6	99.9
ACTS	20.2	2.7	19.2	58.3	16.3	99.9
Isat V & VI	14.0	1.1	8.8	27.4	2.5	99.9
Isat V & VI	11.0	0.1	5.25	16.7	3.7	99.9
DSCS III	8.4	0.4	2.9	9.5	4.0	99.9
DSCS III	7.75	0.3	2.5	8.2	2.0	99.9

Rain Fade Attenuations, Tampa, Florida

A(1.0%) = 1% per yr = 87.6 hrs down, 99% availability

A(0.1%) = 0.1% per yr = 8.76 hrs down, 99.9% availability

A(0.01%) = 0.01% per yr = 52.56 min down, 99.99% available

[1]NASA Rain Rate Charts and Rain Fade Attenuation Formulas taken from: Timothy Pratt and Charles Bostian, Satellite Communications (New York: John Wiley and Sons, 1986), pp. 328-338.

Summary

Denver, Colorado

Satellite System	FREQ GHz	Attenuation in dB A(1.0%)	A(0.1%)	A(0.01%)	Margin dB	Avail.
DSCS F	45.5	1.7	6.3	25.1	16/13	99.99
DSCS F	21.2	0.2	1.3	6.9	6/4	99.99
ACTS	30.0	0.7	2.8	13.0	16.6	≥99.999
ACTS	20.2	0.3	1.3	6.3	16.3	≥99.999
Isat V & VI	14.0	0.11	0.55	2.8	2.5	99.99
Isat V & VI	11.0	0.06	0.32	1.6	3.7	99.999
DSCS III	8.4	0.03	0.17	0.95	4.0	≥99.999
DSCS III	7.75	0.03	0.14	0.8	2.0	≥99.999

Rain Fade Attenuations, Denver, Colorado

Rain Fade Attenuations

1% per yr = 87.6 hrs down, 99% availability

0.1% per yr = 8.76 hrs down, 99.9% availability

0.01% per yr = 52.56 min down, 99.99% availability

Tampa, Florida: Lat. 27.95° N/Long. 82.45° W, height 0.006 km, (Λ_e)
El. = 52.06°

Denver, Colorado: Lat. 39.73° N/Long. 104.98° W, height 1.67 km, (Λ_e)
El. = 43.76°

Rain Rate/% of Year (p)

Tampa: 6mm/hr/1.0%, 35 mm/hr/0.1%, 98 mm/hr/0.01%

Denver: 1.5 mm/hr/1.0%, 6.1 mm/hr/0.1%, 23.5 mm/hr/0.01%

ACTS: x-mit = 20.2 GHz, rcv = 30.0 GHz

DSCS III: x-mit = 7.75 GHz, rcv = 8.4 GHz

DSCS F: x-mit = 21.2 GHz, rcv = 45.5 GHz

Intelsat V & VI: x-mit = 11 GHz, rcv = 14 GHz

$A(p) = a[R]^b L$; $R \leq 10$ mm/hr A = rain attenuation (dB)

$$A(p) = a[R]^b \left\{\frac{1 - \exp[-yb \log_e(\frac{R}{10})L \cos(El)]}{yb \log_e(\frac{R}{10}) \cos(El)}\right\};$$

$R > 10$ mm/hr, $y = 1/22$

$$a = \begin{cases} 4.21 \times 10^{-5} f^{2.42}; & 2.9 \leq f \leq 54 \text{ GHz} \\ 4.09 \times 10^{-2} f^{0.699}; & 54 \leq f \leq 180 \text{ GHz} \end{cases} \qquad f \text{ in GHz}$$

$$b = \begin{cases} 1.41 f^{-0.0779}; & 8.5 \leq f < 25 \text{ GHz} \\ 2.63 f^{-0.272}; & 25 \leq f < 164 \text{ GHz} \end{cases}$$

$L = \dfrac{He - Ho}{\sin(El)}$ km L = path length in rain

Hi = height zero degree isotherm in km,

Ho = Height above sea level in km,

He = effective storm height in km

$$He = \begin{cases} Hi; & R \leq 10 \text{ mm/hr} \\ Hi + \log_{10}(R/10); & R > 10 \text{ mm/hr} \end{cases} \quad \text{km}$$

$$Hi = \begin{cases} 4.8; & \Lambda_e \leq 30^o \\ 7.8 - 0.1|\Lambda_e|; & |\Lambda_e| > 30^o \quad km \end{cases}$$

ACTS

Baseband Processor Mode:

Clear Weather Margin = 6.3 dB (down), 6.6 dB (up)

Plus Auto Rain Fade compensation = 16.3 dB (xmit), 16.6 dB (rcv)

Tampa

Ho = 0.006 km

Hi = 4.8 since $\Lambda_e = 27.45^o \leq 30^o$

He(1.0%) = 4.8 km

He(0.1%) = 4.8 + $\log_{10}$ (35/10) = 4.8 + 0.544 = 5.344 km

He(0.01%) = 4.8 + $\log_{10}$ (98/10) = 4.8 + 0.991 = 5.79 km

$$L(1.0) = \frac{4.8km - 0.006\ km}{\sin(52.06^o)} = \frac{4.794}{0.7886} = 6.079\ km$$

$$L(0.1) = \frac{5.344 - 0.006}{\sin(52.06)} = \frac{5.338}{0.7886} = 6.769\ km$$

$$L(0.01) = \frac{5.79 - 0.006}{\sin(52.06)} = \frac{5.784}{0.7886} = 7.33\ km$$

x-mit (20.2 GHz):

$a = 4.21\ E^{-5} \times 20.2^{2.42} = 0.061$

$b = 1.41 \times 20.2^{-0.0779} = 1.116$

rcv (30.0 GHz):

$a = 4.21\ E^{-5} \times 30^{2.42} = 0.158$

$b = 2.63 \times 30^{-0.272} = 1.043$

A(1.0%):

x-mit (20.2 GHz): $A(1.0) = 0.061(6)^{1.116} \times 6.079 = 2.7389$

or 2.7 dB

rcv (30.0 GHz): $A(1.0) = 0.158(6)^{1.043} \times 6.079 = 6.224$

or 6.2 dB

A(0.1%):

x-mit (20.2 GHz) = $A(0.1) = 0.061\ (35)^{1.116}$

$$\left\{\frac{1 - \exp[-1/22(1.116)\ \log_e(35/10)\ 6.769\ \cos(52.06^o)]}{1/22(1.116)\ \log_e(35/10)\ \cos(52.06^o)}\right\}$$

$$= 3.225\left\{\frac{1 - e^{-0.26448}}{0.03907}\right\} = 3.225\ \left\{\frac{0.23239}{0.03907}\right\} =$$

$3.225\ (5.948) = 19.182$ or 19.2 dB

rcv (30.0 GHz): $A(0.1) = 0.158\ (35)^{1.043}$

$$\left\{\frac{1 - e^{[-1/22(1.043)\ \log_e(35/10)\ 6.769\ \cos(52.06^o)]}}{1/22(1.043)\ \log_e(35/10)\ \cos(52.06^o)}\right\}$$

$$= 6.44\ \left\{\frac{1 - e^{-0.247}}{0.0365}\right\} = 6.444\left\{\frac{0.21886}{0.0365}\right\} =$$

$6.444\ (5.996) = 38.638$ or 38.6 dB

A(0.01%):

x-mit (20.2 GHz): $A(0.01) = 0.61\ (98)^{1.116}$

$$\left\{\frac{1 - e^{[-1/22(1.116)\ \log_e(98/10)\ 7.33\ \cos(52.06^\circ)]}}{1/22(1.116)\ \log_e(98/10)\ \cos(52.06^\circ)}\right\}$$

$$= 10.175\ \left\{\frac{1 - e^{-0.5218}}{0.071}\right\} = 10.175\ \left\{\frac{0.4065}{0.071}\right\} =$$

$10.175\ (5.725) = 58.255$ or 58.3 dB

rcv (30.0 GHz): $A(0.01) = 0.158\ (98)^{1.043}$

$$\left\{\frac{1 - e^{[-1/22(1.043)\ \log_e(98/10)\ 7.33\ \cos(52.06^\circ)]}}{1/22(1.043)\ \log_e(98/10)\ \cos(52.06^\circ)}\right\}$$

$$= 18.858\ \left\{\frac{1 - e^{-0.488}}{0.066}\right\} = 18.858\ \left\{\frac{0.386}{0.066}\right\} =$$

$18.858\ (5.848) = 110.28$ or 110.3 dB

Denver

$Ho = 1.67$ km

$Hi = 7.8 - 0.1(39.73) = 3.827;\ |\Lambda_e| > 30^\circ$

$He(1.0\%) = 3.827$

$He(0.1\%) = 3.827$

$He(0.01\%) = 3.827 + \log(23.5/10) = 4.2$

$$L(1.0) = \frac{3.827 - 1.67\text{km}}{\sin(52.06^\circ)} = \frac{2.157}{0.7886} = 2.735$$

$$L(0.1) = \frac{3.827 - 1.67\text{km}}{\sin(52.06)} = 2.735$$

$$L(0.01) = \frac{4.2 - 1.67\text{km}}{\sin(52.06)} = \frac{2.53}{0.7886} = 3.208$$

x-mit (20.2 GHz): $a = 0.061$, $b = 1.116$

rcv (30.0 GHz): $a = 0.158$, $b = 1.043$

<u>A(1.0%)</u>:

<u>x-mit</u> (20.2 GHz): $A(1.0) = 0.061\ (1.5)^{1.116} \times 2.735 =$

<u>0.3 dB</u>

<u>rcv</u> (30.0 GHz): $A(1.0) = 0.158\ (1.5)^{1.043} \times 2.735 =$

<u>0.7 dB</u>

<u>A(0.1%)</u>:

<u>x-mit</u> (20.2 GHz): $A(0.1) = 0.061\ (6.1)^{1.116} \times 2.735 =$

<u>1.3 dB</u>

<u>rcv</u> (30.0 GHz): $A(0.1) = 0.158\ (6.1)^{1.043} \times 2.735 =$

<u>2.8 dB</u>

<u>A(0.01%)</u>:

<u>x-mit</u> (20.2 GHz): $A(0.01) = 0.061\ (23.5)^{1.116}$

$$\left\{\frac{1 - \exp[-1/22(1.116)\ \log_e(23.5/10)\ 3.208\ \cos(43.76^{\circ})]}{1/22(1.116)\ \log_e(23.5/10)\ \cos(43.76^{\circ})}\right\}$$

$$= 2.07\ \left\{\frac{1 - e^{-0.100}}{0.0313}\right\} = 2.07\ \left\{\frac{0.0952}{0.0313}\right\} = \underline{6.3\ \mathrm{dB}}$$

<u>rcv</u> (30.0 GHz): $A(0.01) = 0.158\ (23.5)^{1.043}$

$$\left\{\frac{1 - \exp[-1/22(1.043)\ \log_e(23.5/10)\ 3.208\ \cos(43.76^{\circ})]}{1/22(1.043)\ \log_e(23.5/10)\ \cos(43.76^{\circ})}\right\}$$

$$4.253\ \left\{\frac{1 - e^{-0.938}}{0.0293}\right\} = 4.253\ \left\{\frac{0.0895}{0.0293}\right\} = \underline{13\ \mathrm{dB}}$$

DSCS III

Clear Weather Margin = xmit: 2 dB; rcv = 4 dB

Tampa

Ho = 0.006 km

Hi = 4.8

He(1.0%) = 4.8 km

He(0.1%) = 5.344 km

He(0.01%) = 5.79 km

L(1.0) = 6.079 km

L(0.1) = 6.769 km

L(0.01) = 7.33 km

x-mit (7.75 GHz)

$a = 4.21\ E^{-5} \times 7.75^{2.42} = 0.00598$

$b = 1.41 \times (7.75)^{-0.0779} = 1.2$

rcv (8.4 GHz)

$a = 4.21\ E^{-5} \times 8.4^{2.42} = 0.0073$

$b = 1.41 \times (8.4)^{-0.0779} = 1.19$

A(1.0%):

x-mit (7.75 GHz): $A(1.0) = 0.00598\ (6)^{1.2} \times 6.079 =$ 0.3 dB

rcv (8.4 GHz): $A(1.0) = 0.0073\ (6)^{1.19} \times 6.079 =$ 0.4 dB

<u>A(0.1%):</u>

<u>x-mit</u> (7.75 GHz): $A(0.1) = 0.00598\ (35)^{1.2}$

$$\left\{\frac{1 - \exp[-1/22(1.2)\ \log_e(35/10)\ 6.769\ \cos(52.06^{\circ})]}{1/22(1.2)\ \log_e(35/10)\ \cos(52.06^{\circ})}\right\}$$

$$= 0.426\ \left\{\frac{1 - e^{-0.28438}}{0.042}\right\} = \underline{2.5\ \text{dB}}$$

<u>rcv</u> (8.4 GHz): $A(0.1) = 0.0073\ (35)^{1.19}$

$$\left\{\frac{1 - \exp[-1/22(1.19)\ \log_e(35/10)\ 6.769\ \cos(52.06^{\circ})]}{1/22(1.19)\ \log_e(35/10)\ \cos(52.06^{\circ})}\right\}$$

$$= 0.5\ \left\{\frac{1 - e^{-0.282}}{0.04166}\right\} = 0.5\ \left\{\frac{0.2457}{0.04166}\right\} = \underline{2.95\ \text{dB}}$$

<u>A(0.01%):</u>

<u>x-mit</u> (7.75 GHz): $A(0.01) = 0.00598\ (98)^{1.2}$

$$\left\{\frac{1 - \exp[-1/22(1.2)\ \log_e(98/10)\ 7.33\ \cos(52.06^{\circ})]}{1/22(1.2)\ \log_e(98/10)\ \cos(52.06^{\circ})}\right\}$$

$$= 1.466\ \left\{\frac{1 - e^{-0.5611}}{0.0765}\right\} = 1.466\left\{\frac{0.4294}{0.0765}\right\} = \underline{8.2\ \text{dB}}$$

<u>rcv</u> (8.4 GHz): $A(0.01) = 0.0073\ (98)^{1.19}$

$$\left\{\frac{1 - \exp[-1/22(1.19)\ \log_e(98/10)\ 7.33\ \cos(52.06^{\circ})]}{1/22(1.19)\ \log_e(98/10)\ \cos(52.06^{\circ})}\right\}$$

$$= 1.7\ \left\{\frac{1 - e^{-0.556}}{0.0759}\right\} = 1.7\ \left\{\frac{0.4265}{0.0759}\right\} = \underline{9.55\ \text{dB}}$$

<u>**Denver**</u>

Ho = 1.67 km

Hi = 3.827

He(1.0%) = 3.827

He(0.1%) = 3.827

He(0.01%) = 4.2

L(1.0) = 2.735

L(0.1) = 2.735

L(0.01) = 3.208

x-mit (7.75 GHz): a = 0.00598, b = 1.2

rcv (8.4 GHz): a = 0.0073, b = 1.19

<u>A(1.0%)</u>:

<u>x-mit</u> (7.75 GHz): $A(1.0) = 0.00598\ (1.5)^{1.2} \times 2.735 =$

<u>0.03 dB</u>

<u>rcv</u> (8.4 GHz): $A(1.0) = 0.0073\ (1.5)^{1.19} \times 2.735 =$

<u>0.03 dB</u>

<u>A(0.1%)</u>:

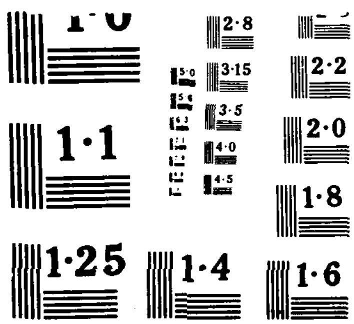
<u>x-mit</u> (7.75 GHz): $A(0.1) = 0.00598\ (6.1)^{1.2} \times 2.735 =$

<u>0.14 dB</u>

<u>rcv</u> (8.4 GHz): $A(0.1) = 0.0073\ (6.1)^{1.19} \times 2.735 =$

<u>0.17 dB</u>

AD-A217 710 NASA'S ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE 2/2
(ACTS): WILL IT BEEEF..(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH C B COSGROVE 1988
UNCLASSIFIED AFIT/CI/CIA-88-242 F/G 22/2 NL


1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.8
3.15
3.5
4.0
4.5
5.0

<u>A(0.01%)</u>:

<u>x-mit</u> (7.75 GHz): $A(0.01) = 0.00598\ (23.5)^{1.2}$

$$\left\{\frac{1 - \exp[-1/22(1.2)\ \log_e(23.5/10)\ 3.208\ \cos(43.76^\circ)]}{1/22(1.2)\ \log_e(23.5/10)\ \cos(43.76^\circ)}\right\}$$

$$= 0.264\ \left\{\frac{1 - e^{-0.108}}{0.0337}\right\} = 0.264\ \left\{\frac{0.1024}{0.0337}\right\} = \underline{0.8\ \text{dB}}$$

<u>rcv</u> (8.4 GHz): $A(0.01) = 0.0073\ (23.5)^{1.19}$

$$\left\{\frac{1 - \exp[-1/22(1.19)\ \log_e(23.5/10)\ 3.208\ \cos(43.76^\circ)]}{1/22(1.19)\ \log_e(23.5/10)\ \cos(43.76^\circ)}\right\}$$

$$= 0.3125\ \left\{\frac{1 - e^{-0.107}}{0.0334}\right\} = 0.3125\ \left\{\frac{0.1015}{0.0334}\right\} = \underline{0.95\ \text{dB}}$$

<u>DSCS Follow On</u>

<u>Link Margin</u>

Earth Station Antenna Diameter	20 ft.	6 ft
x-mit (21.2 GHz) Margin	6 dB	4 dB
rcv (45.5 GHz) Margin	16 dB	13 dB

<u>Tampa</u>

Ho = 0.006 km

Hi = 4.8

He(1.0%) = 4.8 km

He(0.1%) = 5.334 km

He(0.01%) = 5.79 km

L(1.0) = 6.079 km

L(0.1) = 6.769 km

L(0.01) = 7.33 km

x-mit (21.2 GHz)

$$a = 4.21\ E^{-5} \times 21.2^{2.42} = 0.068$$

$$b = 1.41 \times 21.2^{-0.0779} = 1.11$$

rcv (45.5 GHz)

$$a = 4.21\ E^{-5} \times 45.5^{2.42} = 0.433$$

$$b = 2.63 \times 45.5^{-0272} = 0.93$$

<u>A(1.0%)</u>:

<u>x-mit</u> (21.2 GHz): $A(1.0) = 0.068\ (6)^{1.11} \times 6.079 = \underline{3\ \text{dB}}$

<u>rcv</u> (45.5 GHz): $A(1.0) = 0.433\ (6)^{0.93} \times 6.079 = \underline{13.9\ \text{dB}}$

<u>A(0.1%)</u>:

<u>x-mit</u> (21.2 GHz): $A(0.1) = 0.068\ (35)^{1.11}$

$$\left\{\frac{1 - \exp[-1/22(1.11)\ \log_e(35/10)\ 6.769\ \cos(52.06^\circ)]}{1/22(1.11)\ \log_e(35/10)\ \cos(52.06^\circ)}\right\}$$

$$3.52\ \left\{\frac{1 - e^{-0.263}}{0.039}\right\} = 3.52\ \left\{\frac{0.231}{0.039}\right\} = \underline{20.8\ \text{dB}}$$

<u>rcv</u> (45.5 GHz): $A(0.1) = 0.433\ (35)^{0.93}$

$$\left\{\frac{1 - \exp[-1/22(0.93)\ \log_e(35/10)\ 6.769\ \cos(52.06^\circ)]}{1/22(0.93)\ \log_e(35/10)\ \cos(52.06^\circ)}\right\}$$

$$= 11.82\ \left\{\frac{1 - e^{-0.22}}{0.0326}\right\} = 11.82\left\{\frac{0.197}{0.0326}\right\} = \underline{71\ \text{dB}}$$

<u>A(0.01%)</u>:

<u>x-mit</u> (21.2 GHz): $A(0.01) = 0.068\ (98)^{1.11}$

$$\left\{\frac{1 - \exp[-1/22(1.11)\ \log_e(98/10)\ 7.33\ \cos(52.06^o)]}{1/22(1.11)\ \log_e(98/10)\ \cos(52.06^o)}\right\}$$

$$= 10.54\ \left\{\frac{1 - e^{-0.519}}{0.071}\right\} = 10.54\ \left\{\frac{0.4049}{0.071}\right\} = \underline{60.1\ dB}$$

<u>rcv</u> (45.5 GHz): $A(0.01) = 0.433\ (98)^{0.93}$

$$\left\{\frac{1 - \exp[-1/22(0.93)\ \log_e(98/10)\ 7.33\ \cos(52.06^o)]}{1/22(0.93)\ \log_e(98/10)\ \cos(52.06^o)}\right\}$$

$$= 30.78\ \left\{\frac{1 - e^{-0.435}}{0.059}\right\} = 30.78\ \left\{\frac{0.3527}{0.059}\right\} = \underline{184\ dB}$$

<u>Denver</u>

Ho = 1.67 km

Hi = 3.827 km

He(1.0%) = 3.827

He(0.1%) = 3.827

He(0.01%) = 4.2

L(1.0) = 2.735

L(0.1) = 2.735

L(0.01) = 3.208

x-mit (21.2 GHz): a = 0.068, b = 1.11

rcv (45.5 GHz): a = 0.433, b = 0.93

A(1.0%):

x-mit (21.2 GHz): $0.068\ (1.5)^{1.11} \times 2.735 = \underline{0.29\ \text{dB}}$

rcv (45.5 GHz): $0.433\ (1.5)^{0.93} \times 2.735 = \underline{1.73\ \text{dB}}$

A(0.1%):

x-mit (21.2 GHz): $0.068\ (6.1)^{1.11} \times 2.735 = \underline{1.38\ \text{dB}}$

rcv (45.5 GHz): $0.433\ (6.1)^{0.93} \times 2.735 = \underline{6.36\ \text{dB}}$

A(0.01%):

x-mit (21.2 GHz): $A(0.01) = 0.068\ (23.5)^{1.11}$

$$\left\{\frac{1 - \exp[-1/22(1.11)\ \log_e(23.5/10)\ 3.208\ \cos(43.76^{\circ})]}{1/22(1.11)\ \log_e(23.5/10)\ \cos(43.76^{\circ})}\right\}$$

$$= 2.26\ \left\{\frac{1 - e^{-0.0999}}{0.0311}\right\} = 2.26\ \left\{\frac{0.095}{0.0311}\right\} = \underline{6.9\ \text{dB}}$$

rcv (45.5 GHz): $A(0.01) = 0.433\ (23.5)^{0.93}$

$$\left\{\frac{1 - \exp[-1/22(0.93)\ \log_e(23.5/10)\ 3.208\ \cos(43.76^{\circ})]}{1/22(0.93)\ \log_e(23.5/10)\ \cos(43.76^{\circ})}\right\}$$

$$= 8.16\ \left\{\frac{1 - e^{-0.0837}}{0.026}\right\} = 8.16\left\{\frac{0.08}{0.026}\right\} = \underline{25.1\ \text{dB}}$$

Intelsat V and VI

11/14 GHz segment

Link Margin

x-mit (11 GHz): 3.7 dB

rcv (14 GHz): 2.5 dB

Tampa

Ho = 0.006 km

Hi = 4.8 km

He(1.0%) = 4.8 km

He(0.1%) = 5.334 km

He(0.01%) = 5.79 km

L(1.0) = 6.079 km

L(0.1) = 6.769 km

L(0.01) = 7.33 km

x-mit (11 GHz):

$a = 4.21\ E^{-5} \times (11)^{2.42} = 0.0139$

$b = 1.41\ (11)^{-0.0779} = 1.17$

rcv (14 GHz):

$a = 4.21\ E^{-5} \times (14)^{2.42} = 0.025$

$b = 1.41\ (14)^{-0.0779} = 1.148$

A(1.0%):

x-mit (11 GHz): $A(1.0) = 0.0139\ (6)^{1.17} \times 6.079 = \underline{0.11\ \text{dB}}$

rcv (14 GHz): $A(1.0) = 0.025\ (6)^{1.148} \times 6.079 = \underline{1.19\ \text{dB}}$

A(0.1%):

x-mit (11 GHz): $A(0.1) = 0.0139\ (35)^{1.17}$

$$\left\{\frac{1 - \exp[-1/22(1.17)\ \log_e(35/10)\ 6.769\ \cos(52.06^o)]}{1/22(1.17)\ \log_e(35/10)\ \cos(52.06^o)}\right\}$$

$$= 0.89\ \left\{\frac{1 - e^{-0.277}}{0.041}\right\} = 0.89\ \left\{\frac{0.2419}{0.041}\right\} = \underline{5.25\ dB}$$

rcv (14 GHz): $A(0.1) = 0.025\ (35)^{1.148}$

$$\left\{\frac{1 - \exp[-1/22(1.148)\ \log_e(35/10)\ 6.769\ \cos(52.06^o)]}{1/22(1.148\ \log_e(35/10)\ \cos(52.06^o)}\right\}$$

$$= 1.481\ \left\{\frac{1 - e^{-0.272}}{0.04}\right\} = 1.481\ \left\{\frac{0.238}{0.04}\right\} = \underline{8.8\ dB}$$

A(0.01%):

x-mit (11 GHz): $A(0.01) = 0.0139\ (98)^{1.17}$

$$\left\{\frac{1 - \exp[-1/22(1.17)\ \log_e(98/10)\ 7.33\ \cos(52.06^o)]}{1/22(1.17)\ \log_e\ (98/10)\ \cos(52.06^o)}\right\}$$

$$= 2.97\ \left\{\frac{1 - e^{-0.547}}{0.075}\right\} = 2.97\ \left\{\frac{0.421}{0.075}\right\} = \underline{16.7\ dB}$$

rcv (14 GHz): $A(0.01) = 0.025\ (98)^{1.148}$

$$\left\{\frac{1 - \exp[-1/22(1.148)\ \log_e(98/10)\ 7.33\ \cos(52.06^o)]}{1/22(1.148)\ \log_e(98/10)\ \cos(52.06^o)}\right\}$$

$$4.83\ \left\{\frac{1 - e^{-0.537}}{0.073}\right\} = 4.83\ \left\{\frac{0.415}{0.073}\right\} = \underline{27.4\ dB}$$

Denver

Ho = 1.67 km

Hi = 3.827 km

He(1.0%) = 3.827

He(0.1%) = 3.827

He(0.01%) = 4.2

L(1.0) = 2.735

L(0.1) = 2.735

L(0.01) = 3.208

x-mit (11 GHz): a = 0.0139, b = 1.17

rcv (14 GHz): a = 0.025, b = 1.148

<u>A(1.0%)</u>:

<u>x-mit</u> (11 GHz): $A(1.0) = 0.0139\ (1.5)^{1.17} \times 2.735 =$

<u>0.06 dB</u>

<u>rcv</u> (14 GHz): $A(1.0) = 0.025\ (1.5)^{1.148} \times 2.735 =$

<u>0.11 dB</u>

<u>A(0.1%)</u>:

<u>x-mit</u> (11 GHz): $A(0.1) = 0.0139\ (6.1)^{1.17} \times 2.735 =$

<u>0.32 dB</u>

<u>rcv</u> (14 GHz): $A(0.1) = 0.025\ (6.1)^{1.148} \times 2.735 =$

<u>0.55 dB</u>

A(0.01%):

x-mit (11 GHz): $A(0.01) = 0.0139\ (23.5)^{1.17}$

$$\left\{\frac{1 - \exp[-1/22(1.17)\ \log_e(23.5/10)\ 3.208\ \cos(43.76^{\circ})]}{1/22(1.17)\ \log_e(23.5/10)\ \cos(43.76^{\circ})}\right\}$$

$$= 0.559\ \left\{\frac{1 - e^{-0.105}}{0.033}\right\} = 0.559\ \left\{\frac{0.0997}{0.033}\right\} = \underline{1.69\ \text{dB}}$$

rcv (14 GHz): $A(0.01) = 0.025\ (23.5)^{1.148}$

$$\left\{\frac{1 - \exp[-1/22(1.148)\ \log_e(23.5/10)\ 3.208\ \cos(43.76^{\circ})]}{1/22(1.148)\ \log_e(23.5/10)\ \cos(43.76^{\circ})}\right\}$$

$$= 0.937\ \left\{\frac{1 - e^{-0.103}}{0.032}\right\} = 0.937\ \left\{\frac{0.0979}{0.032}\right\} = \underline{2.87\ \text{dB}}$$